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1983
ANNUAL
REVIEW
OF
ACTIVITIES



Institute of Ocean Sciences

1983 ANNUAL REVIEW OF ACTIVITIES

Institute
of
Ocean Sciences



Institute of Ocean Sciences with the Marine Technology Centre in the background.

1983 ANNUAL REVIEW OF ACTIVITIES

Institute of Ocean Sciences
PATRICIA BAY, SIDNEY, B.C.



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 du Canada

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DEPARTMENT OF FISHERIES AND OCEANS

Director-General's Foreword



In 1983 approval was obtained to proceed with the construction of a replacement vessel for the *Wm. J. Stewart*. The keel was laid at the Bel Aire shipyard in North Vancouver in January 1984 and the ship is expected to be completed by December 1984. The new ship, and the *Parizeau*, provide IOS with two ships capable of operating in the open ocean, one of which is capable of work in the Arctic as the new ship is ice strengthened. The impact of the program will be tremendous as it will give IOS the opportunity to plan offshore and arctic programs with the assurance that a ship will be available to carry them out. In the past we have had to rely on chartering a second ship or on *Hudson* coming around from the East coast. Either of these could only be arranged if the task was extremely urgent and short-lived.

Hydrography is a major beneficiary of the new ship as it is first of all designed as a replacement for the *Wm. J. Stewart* which undertook offshore surveying of the Pacific coast. When she was taken out of service any systematic surveying of the Pacific coast was abandoned, partly because of commitments in the Beaufort Sea, but largely because there was no ship available other than *Parizeau* and only limited time was available on her. With the new ship we will be able to resume our charting of offshore areas and also to continue with surveying in the western Arctic.

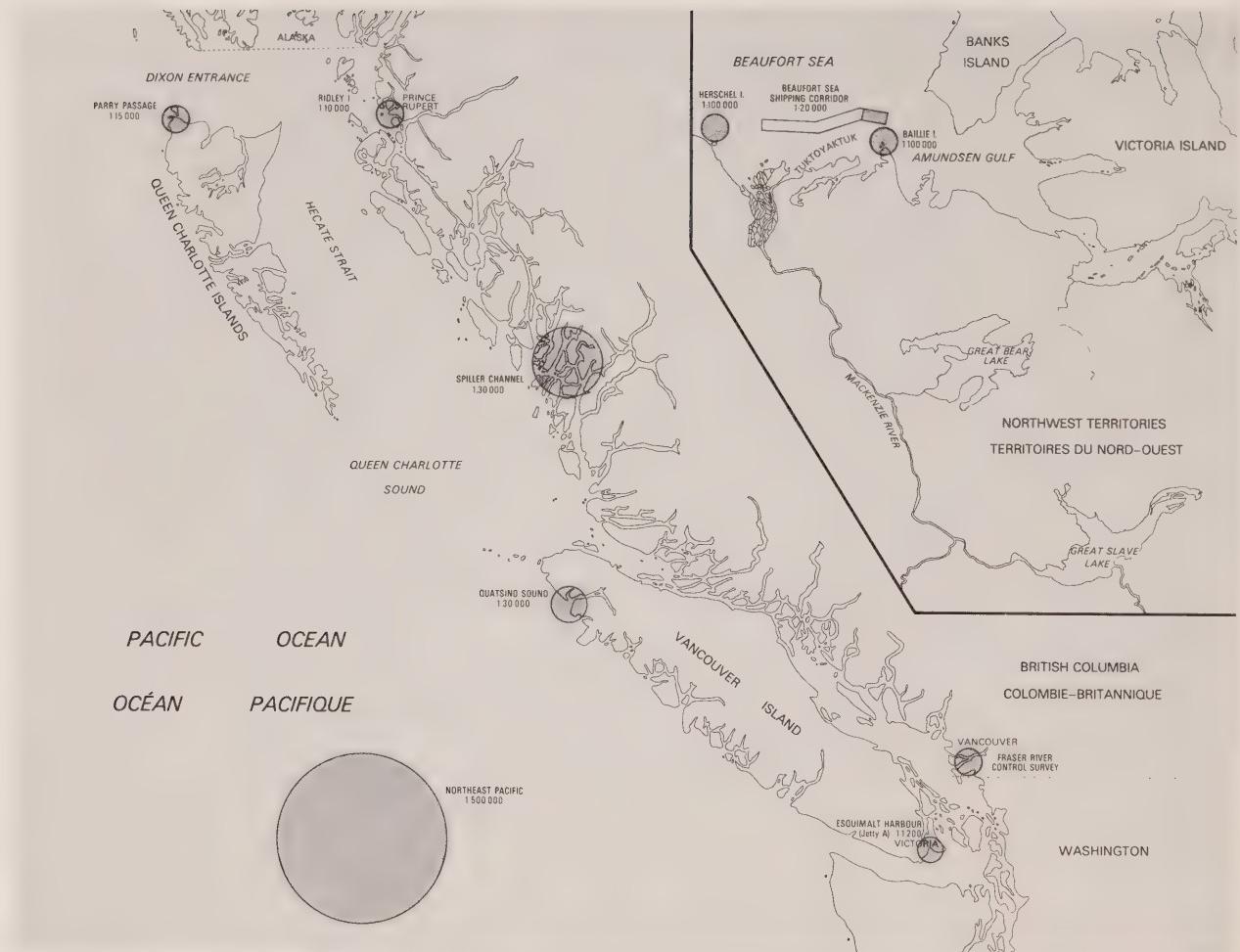
For oceanography sufficient ship time will be available to develop a Pacific-wide program in cooperation with other countries on the Pacific Rim. In the past the Pacific deep sea program was based on observations from the weatherships which provided an invaluable time series in waters adjacent to Canada. Following the withdrawal of the weatherships we attempted to continue the time series and our studies of waters adjacent to Canada but with only partial success owing to lack of ship time. Also it was only possible to send a ship to distant waters every 5-7 years, with no follow-up, so that no cohesive long term program could be thought of, let alone executed. Both these restrictions will be removed and we will be able to plan a deep sea program in Canadian and distant waters knowing that we will have sufficient ship time to implement them.

Another factor that is influencing the program is the acquisition of considerable sums of money, and a few person years, through the OERD program and the Transport R&D program, and it appears we will be funded through the NOGAP and Climate programs in the future. About one half of our operation O&M will come from these programs. The funds are tied to specific project objectives and they draw with them staff and funds from our A-Base so they are having a great influence on the direction of the IOS program. The objectives are specific, applied, and short term.

We will have to take some care that they do not pre-empt the longer term research and surveying that we support with our A-Base resources. So far, however, the acquisition of these funds has been beneficial as we have been able to design programs using a combination of A-Base and external resources that satisfy both objectives.

The disappointing aspect of the year's efforts is that I have been unsuccessful in making the point that IOS is a new institute with not enough staff to respond to the challenges of hydrography and oceanography in the Arctic and Pacific. It is my intention to continue to press the point as it is my conviction that it is reasonable, right, and will be recognized.

Hydrography



Pacific Region 1983 hydrographic survey program.

Hydrography



The main objective of the Hydrographic Division is to provide accurate, timely bathymetric and navigational information in the form of nautical charts, tide tables, current atlases and sailing directions for commercial and recreational users. Additional information is provided to other federal government agencies, engineering and consulting firms, universities, environmental groups and the general public.

This year saw the completion of surveys of the navigational corridor through the Beaufort Sea, in addition to new surveys and revisory surveys for the continuing charting program on the Pacific coast. A new tidal current atlas, covering the Juan de Fuca Strait and Strait of Georgia, was published and well received by the maritime community. Chart sales continued at a steady pace, consistent with previous years. Good progress was achieved in converting charts to the metric/bilingual format, and with the Loran-C latticing of west coast charts.

Field Hydrography



The Field Hydrography Section is responsible for conducting hydrographic surveys of the B.C. coast, western Arctic and navigable inland waters in the Pacific Region in order to ensure that requirements for navigational information are met. Alterations of, and additions to traffic routes, types and sizes of vessels, harbours, bottom topography and coastlines—all require an ongoing and resurvey program.

The major coastal survey party was assigned to the barge *Pender* from April to October. A resurvey of the Spiller Channel, Bella Bella area of the coast, which included the previously unsurveyed inlets of Bullock and Briggs and Gunboat Passage Narrows was completed. (*Contact: G.E. Richardson.*)

M.V. *Polar Circle* commenced her season at the northwest point of the Queen Charlotte Islands to carry out a resurvey of Parry Passage. The Admiralty last carried out surveys here in the early 1900s. The ship completed this survey in late June and sailed for the western Arctic in early July. Passage to Tuktoyaktuk was slow due to bad ice conditions.

The survey of the Beaufort Sea deep-draught shipping corridor was completed as was a standard survey north of the Baillie Islands connecting the eastern Beaufort Sea and western Amundsen Gulf survey areas of earlier seasons. An early onset of ice precluded much work on a planned survey west of Herschel Island and the ship departed for Halifax the first week of September. (*Contact: A.R. Mortimer.*)

C.S.S. *Richardson* left IOS in late April and made passage to Winter Harbour to continue the surveys of the entrance of Quatsino Inlet commenced in 1982. This

survey was broken off at the end of June with about 80 shoal examinations remaining to be done.

The *Richardson* survey party then moved to Ridley Island (Prince Rupert), the site of a new grain and coal terminal. New surveys were required for new charting in the area prior to the arrival of the first deep-draught carriers. This survey was 95% completed by October when the party returned to base. The remaining area was completed in early December when the construction equipment was removed. Shallow coring was carried out in potential anchorage areas and the cores were passed to Pacific Geoscience Centre (PGC) for analysis. (*Contact: J.V. Crowley.*)

Several small local survey projects were carried out from IOS. These included Tsehum Harbour, Esquimalt Harbour, Bamfield, Fraser River and Vancouver Harbour. (*Contact: B.M. Lusk.*)

Three Unsolicited Proposals from the private sector were considered this past year. One dealt with the survey of artificial Arctic islands from a fixed wing aircraft. The investigator was successful and proved that these islands can be monitored effectively in this manner. (*Contact: J. Vosburgh.*) The second proposal is still in progress and deals with the automated plotting of contours. A final edition of this software will be delivered in March of 1984. (*Contact: J. Vosburgh.*) The third proposal deals with the digital transfer of information from aerial photographs to field survey sheets and at this time is being analyzed for compatibility with present methods. (*Contact: B.M. Lusk.*)

Surveys for chart and sailing directions revisions were carried out under contract.

A contract was awarded for horizontal control in the western Arctic between Herschel Island and the Yukon/Alaska boundary and was completed.

Sailing Directions

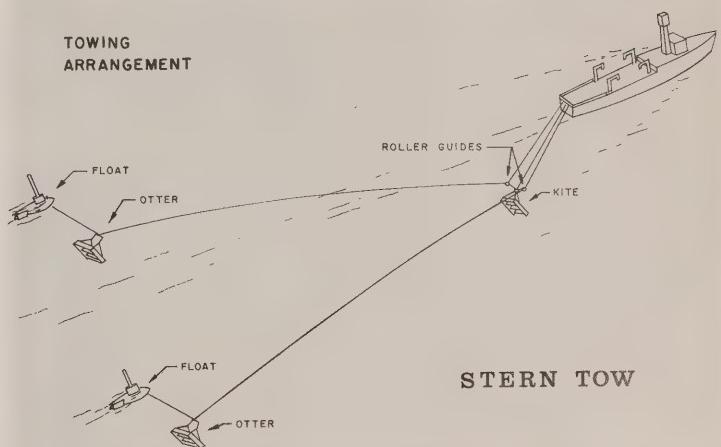
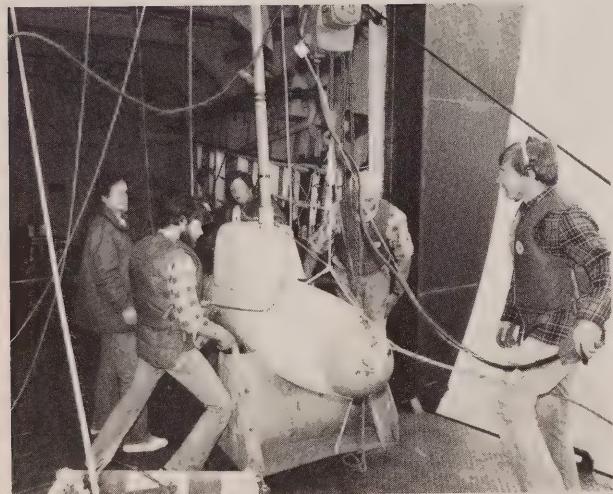
The Ninth Edition of the *British Columbia Coast Sailing Directions (North Portion)*, Volume II, was published in May. This edition includes new information on tidal streams, seabed, vessel traffic services, Loran-C and port facilities. New photography and several new diagrams were incorporated into this edition. Volume II and Volume I (South Portion) are published in alternate years. (*Contact: Volume I, A. Smith; Volume II, J. Roberts.*)

Due to marketing considerations, *Small Craft Guide*, Volume I, 6th Edition, was held back from a spring release until November. It will be back in phase for the 7th Edition. (*Contact: L.M. Wakefield.*)

Responsibility for the *Arctic Pilot*, Volume III, was transferred to Pacific Region in 1983.

Hydrographic Development

A major project undertaken this year was the implementation of the Stern Tow sounding system to generate a greater volume of data for surveys such as the Beaufort Sea Corridor. Stern Tow was used and tested for a short period to improve the towing configuration. The Hydrographic Acquisition and Logging (HAL) data logger, an off-shoot of the Stern Tow, was built over the winter and used extensively in the Beaufort Sea. This new generation data logger, providing more, and better, data at greater frequency has necessitated new processing software.



Deployment of the Stern Tow sounding system in the Beaufort Sea.

The previously mentioned bathymetric contouring contract was also part of hydrographic development activities this year. The first two phases of this four phase project have now been completed, and preliminary plots have recently been presented for review.

Field evaluation of Sea Marc II was conducted, in conjunction with Engineering Services and PGC, off the west coast of Vancouver Island on a cruise on board the University of Hawaii's research vessel *Kana Keoki*. Conclusions are not yet available.

○ ○ ○ ○ Chart Production and Distribution

The functions of Chart Production and Distribution are to ensure that survey and other data are processed for publication as expeditiously as possible and to ensure that a ready supply is on hand for all users.

Twelve new standard charts were produced in Pacific Region this year in addition to 48 new editions and 13 reprints. A heavy load of hand amendments precipitated the preparation of 15 over-printings and 13 chart amendment patches were required. The Distribution Centre handled requests for 195,000 charts and 70,000 publications during the year.

Eighteen Notices to Shipping and 120 Notices to Mariners were issued, necessitating 160 chart amendment tracings, and 436 MAREP (the Canadian Power Squadron's Marine Reporting Program) reports were processed.

Four staff attended CARTO I, two senior staff attended the CARTO II training program and another participated in an exchange assignment with CHS' sister organization in the U.S., NOAA (National Oceanic and Atmospheric Administration).

A VAX-11/750 minicomputer system was delivered and the latter half of 1983 was spent converting software from the PDP-11/34. The system, providing much faster file processing and multiple simultaneous use, was tested successfully and will be integrated into the production routine early in 1984.

Promotional and educational activities continued with participation in two boat shows in B.C. and other activities such as tours and lectures. The new "Current Atlas: Juan de Fuca Strait to Strait of Georgia" was successfully launched at the Vancouver Boat Show and the initial printing subsequently sold-out before year's end.

The chart inventory and control system, initiated last year, was adapted to use six years of sales data as a base and is working well.

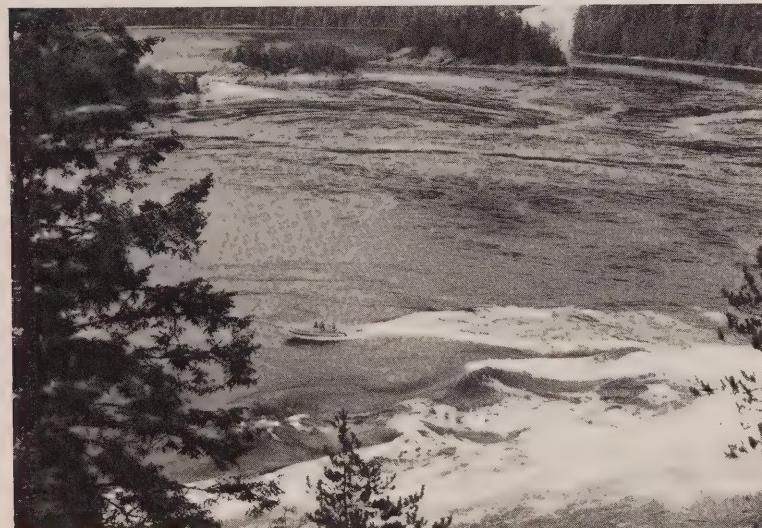
○ ○ ○ ○ Tidal and Current Surveys ○ ○ ○ ○

A study of the circulation in the waters surrounding the Queen Charlotte Islands, started in Queen Charlotte Sound in 1982, continued into Hecate Strait, and, in collaboration with Offshore Oceanography, into the area of the west coast of the Queen Charlotte Islands. Moorings of current meters and tide gauges will be serviced at four month intervals for two years.

Preliminary results from satellite-tracked drifters in these waters illustrate several of the important features of these basins. Waters in the central portion of Queen

Charlotte Sound do not appear to follow an average flow pattern, but exhibit a moving pattern of eddies. This was suspected from an analysis of current meter records from the 1982 survey and also is reflected on the drifter tracks. One of the drifters, released on September 9, 1983, was trapped in these gyres for over a month until a storm in late October carried it into Hecate Strait. It is suspected that the relatively narrow width of Hecate Strait prevents the formation of eddies and gyres, especially in late fall and winter during strong southeast winds. The drifter was carried along the Strait, across Dixon Entrance and into Clarence Strait in Alaska. Subsequently, its motion reversed; it was carried back into Dixon Entrance, where it remained for several weeks until it exited into the North Pacific, 80 days after release. Its track showed sustained uniform motion only in Hecate Strait. The irregular motion elsewhere will be studied in detail in future work. (*Contact: W.R. Crawford, W.S. Huggett.*)

Plans to gather additional data from drifters in Dixon Entrance proceeded by means of contract to develop and deploy Loran-C tracked drifters. These are to give frequent and accurate position, permitting the resolutions of tidal and inertial period motions.



Measuring the current in Sechelt Rapids; here the current is flooding at 13 knots.

A turbulence profiler to look at shallow water and continental shelf mixing processes was built according to existing designs and modified with a unique guard to enable employment closer to the bottom. This profiler was used, with success, on two separate cruises in Hecate Strait. (*Contact: W.R. Crawford.*)

In the Canadian Arctic, a multi-year program to increase knowledge of long-term mean sea level variations in waters contiguous to the Arctic archipelago was continued. Six water level recorders at permanent gauging sites in the western Arctic

were operated and a gauge at Baychimo was deployed for the purpose of determining mean sea level for the Geodetic Survey. (*Contact: F.E. Stephenson.*)

Four experimental current meters were deployed and recovered in Dease Strait. Unfortunately, data recovery was disappointing, but the difficulties with the instruments have been determined and are being resolved. (*Contact: M.J. Woodward.*)

Inspection, maintenance and operation of several temporary tide gauges and two Tsunami Warning gauges on the coast of British Columbia was carried out on a routine basis. Data from these gauges, as well as from 17 permanent tide gauges, are routinely sent to Marine Environmental Data Service (MEDS). Work has been carried out on the acquisition of two meteor-burst data transmitting systems, to relay data to the Institute from remote gauge locations. (*Contact: F.E. Stephenson.*)

Model studies of tides, currents and salinities in the Fraser River were continued. Numerous model runs were produced by request of various groups and agencies. Model runs of a prediction model for oil spill movement were made upon request. (*Contact: A.B. Ages.*)

Current surveys were carried out in Nakwakto Rapids and Sechelt Rapids in order to improve predictions in these fast-flowing narrows. The survey in Nakwakto Rapids will have to be repeated due to malfunctioning instruments. The survey in Sechelt Rapids was successful. (*Contact: M.J. Woodward.*)

Tsunamis

The tsunami of May 26, 1983 in the Sea of Japan with the loss of 100 lives is once again a reminder of the threat these destructive waves pose to communities on the coasts of the Pacific Ocean. Recognizing that preparedness can save lives and reduce property damage, IOS participated with federal, provincial and municipal agencies in two exercises in 1983 to test the warning systems in B.C.'s coastal communities. Valuable lessons were learned, and tests may be conducted yearly.

Research continued on the historical knowledge of tsunamis that can be applied to hazard evaluation and mitigation. In cooperation with PGC, studies are in progress on the tsunami-generating potential of submarine landslides on delta fronts, with particular interest at this time in the Fraser Delta.

International cooperation has been extended in helping to improve the Tsunami Warning System in the Pacific. The Tsunami Warning Centre at Palmer Alaska assumed regional responsibility in 1983 for the Canadian west coast. (*Contact: S.O. Wigen.*)

Diving Unit

Diving activity in 1983 remained at about the same level as in 1982. Approximately 100 dives were carried out, with the majority being to install or recover bottom-mounted pressure gauges. Major project areas this year were Alice Arm, Queen Charlotte Sound, Hecate Strait and the west coast of the Queen Charlotte Islands. Pressure gauges installed on either side of Sechelt Rapids and Nakwakto Rapids were also serviced several times during the year. Closer to home there was some activity at the CEPEX bag site and hull inspections for *Richardson*, *Pender* and *Vector* were carried out.

In the Arctic, both Frozen Sea Research Group and Tidal and Current Surveys benefitted tremendously from the use of commercial contract divers to recover water level gauges and current meters through the ice. (*Contact: F.E. Stephenson*).



Recovering a tide gauge from the west side of the Arctic's Queen Elizabeth Islands.

Engineering Services



Engineering Services provides electronic and mechanical engineering, electronics support for hydrographic surveys, oceanographic research and ship operations, and an industrial liaison service promoting interaction between IOS, other government departments, and the private sector. (*Contact: T.A. Curran*.)

Engineering Development

This group provides custom development of instrument systems, contract management of government-funded private sector developments, and ongoing electronic/mechanical consultations to all IOS groups.

Continued progress was made on the Active Drifter concept and prototype. A hull was constructed and field-tested in rough waters, and demonstrated good stability. Solar panels charging lead-acid batteries provided power. A Wagner autopilot was used to provide steering control. Work remains in the areas of power management and buoy positioning. It is hoped that commercial exploitation of the technology will occur.

A launch datalogger for hydrography was developed as a result of the Stern Tow project. It is continuing to receive software development support and a PILP (Program for Industry/Laboratory Projects) proposal has been prepared by a local company for NRC (National Research Council) funding to refine the system and to market it worldwide.

Other instrumentation projects included a beam attenuance meter for Ocean Ecology Division, a hand-held current meter for Tidal and Current Surveys and implementation of the SAIL system on the *Parizeau* and *Vector*.

Contract management is consuming a larger proportion of the group's time. The Correlation Sonar contract, phases III and IV, will result in acoustic remote sensing units which can produce a profile of current speed as a function of depth when located on the sea surface or the ocean bottom. Another contract will result in a novel pressure sensor using backscattered light into a laser diode cavity. Several tools of use to a spectrum of submersible users are being designed for *Pisces* IV. Finally, IOS is involved in two proposals to measure forces produced by sea ice.

Formal consultation to other IOS groups has been provided to Tidal and Current Surveys for their Meteorburst tidal telemetry system, to Field Hydrography Section for a range-bearing study, and to Ocean Chemistry Division for a photoacoustic detector project.

Electronics Technology Support

Calibration, repair and installation to support ships, hydrographic and oceanographic programs were satisfactorily performed during the year. The major equipment areas were radios, depth sounders, and positioning systems.

In the radio area, approximately 55 VHF/FM and 15 HF/SSB transceivers were maintained. Three obsolete HF/SSB transceivers were replaced with synthesized

multi-channel equipment. A BH-30 transceiver was increased in channel capacity and a CH150/BH-30 was interfaced to a new model 1 KW antenna coupler. A radio base station was installed at Tuktoyaktuk for radio communications with the charter vessel *Polar Circle* and radio station XMH59 at IOS and in contrast to last year, good communications were experienced. Efforts were expended in obtaining Department of Communications approval for an IOS RITY installation, and a watching brief was maintained over a HF data message terminal for possible IOS use.

The depth sounder group maintained 28 depth sounders plus numerous small sounders from four different manufacturers. Ten depth digitizers were serviced and a contract was awarded to upgrade them to H-series performance. A development contract was completed which saw three 50 KHz digitizers delivered to IOS and two 30 KHz digitizers to CHS Central Region. A short contract resulted in ten digital speed-of-sound circuits retrofitted into existing Skipper sounders. A sounder calibrator resulted in a Suggestion Award and a PILP award to industry.

Approximately 21 microwave positioning units, 15 Argo units, three satellite navigation systems, and Loran-C and Omega systems were serviced. Ships, launches and the barge *Pender* were fitted out for hydrographic purposes.

Support was provided to Computing Services in maintenance of the Kongsberg drafting system and new UNIVAC data circuits. (*Contact: W.R. Taylor.*)

Industrial Liaison and Contracting

The Institute of Ocean Sciences has an established policy of conducting a significant portion of its program through contracts to the private sector.

In addition to contracting out directly, IOS participants in such government ventures as the Unsolicited Proposals (UP) program with the Department of Supply and Services (DSS), and both the Program for Industry/Laboratory Projects (PILP) and the Industrial Research Assistance Program (IRAP) with the National Research Council (NRC). IOS was involved to some extent in 116 contracts in the past year, ranging in value from less than one thousand dollars to approximately one million dollars, and with a total value in excess of \$4.8 million. (*Contact: T.A. Curran.*)

Oceanography

Oceanography



The oceanographic program at IOS includes ocean physics, ocean chemistry and ocean ecology. The oceanographic information on current systems and associated temperatures and salinities, on the chemistry of the ocean and associated pollutants, and on primary productivity and the lower trophic levels of the food chain, such as plankton, are provided to agencies engaged in environmental protection, to fisheries managers, to industrial concerns, defence, and to others who have a need for information about the oceans.

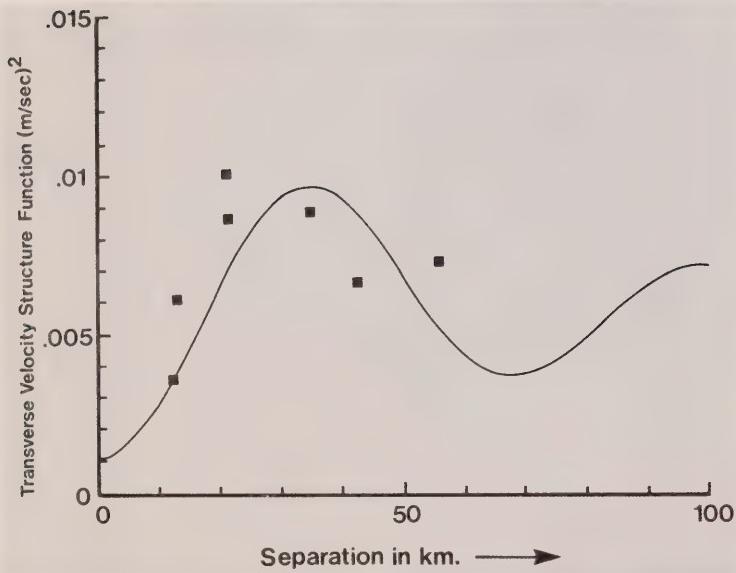
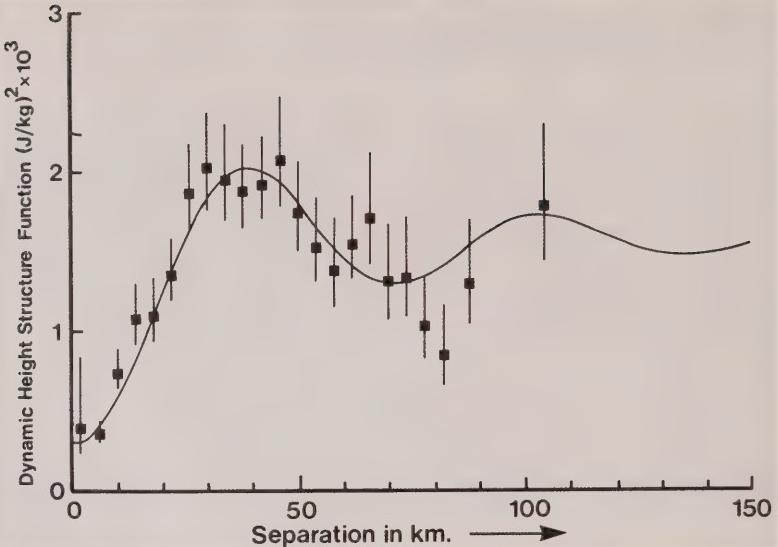
Ocean Physics



The highlights of 1983 include some new developments and some activities which can be viewed as logical extensions of previous projects. Examples of the former would be the initiation of programs to examine oceanographic factors affecting sea ice motion in the Beaufort Sea, and the establishment of a program aimed at the development of methods of forecasting oceanic variables. Examples of extensions of ongoing work are the start of a field program to improve knowledge of the water properties and currents on the west coast of the Queen Charlotte Islands, and the first phase of an international experiment off Australia designed to test theories of continental shelf wave propagation. Other exciting developments came in the area of acoustic remote sensing of the ocean interior and optical remote sensing of near surface properties. However, any such short list is bound to be misleading as the great variety of activities described below will show.

Coastal Zone Oceanography

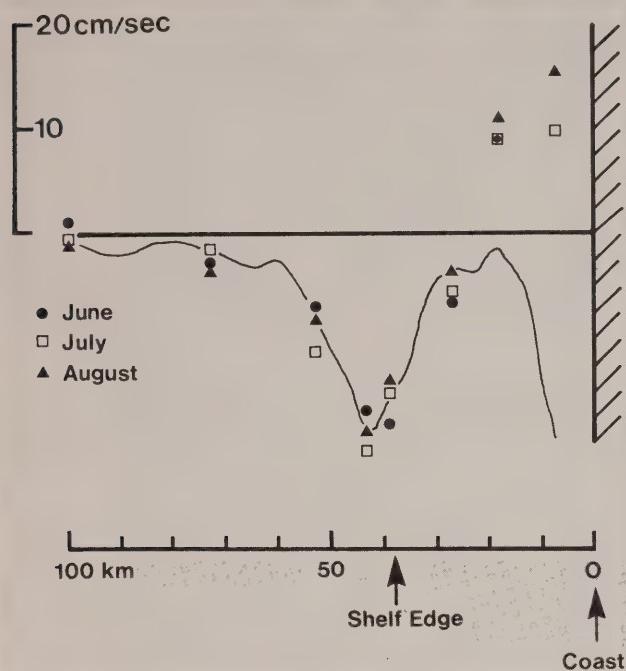
Data acquired between 1979 and 1981 as part of the Coastal Ocean Dynamics Experiment (CODE) continued to produce results. An analysis of the statistical structure of oceanographic fields on the continental shelf demonstrates how dynamical constraints affect the structure of oceanographic fields. Given a prior knowledge of the structure of one field, e.g. the structure function of the dynamic height field, one can predict what the structure function of a related field, e.g. current velocities, should be. In this case the two fields are constrained by the dynamics of geostrophic balance. Operationally this information is of value in planning experiments. Historical data is usually in the form of conductivity and temperature versus depth. These can be used to estimate the dominant scales over which current fields will vary and so can be used to plan a current sampling scheme rationally. (*Contact: H.J. Freeland.*)



The upper panel shows estimates of the structure function $S(\rho)$ of the dynamic height field $D(x)$ plotted against scalar displacement $\rho = |\xi|$, where $S(\rho) = \{D(x) - D(x+\xi)\}^2$. The continuous line is a weighted least-squares fit of a simple functional form for the structure function $S(\rho) = 2\sigma^2\{1 - (1 - \epsilon) \exp(-\rho^2/a^2) J_0(\rho/b)\}$, where σ^2 is the signal variance, ϵ is the noise level and a and b are two length scales. From that least-squares fit we can compute the expected transverse velocity structure function that is implied by geostrophy. This is plotted on the lower panel together with estimates of the structure function derived directly from the current meter observations. This plot indicates that the entire CODE data set is essentially in geostrophic balance, furthermore, the least-squares fit requires that $a \gg b$ which indicates that the current field may be dominated by a few plane waves moving through the CODE area in geostrophic balance.

Current meter observations acquired as the result of several discrete experiments off the B.C. coast since 1979, involving Coastal Zone Oceanography, Offshore Oceanography and Tidal and Current Surveys, were merged into one large synthetical description of the general current regime off the west coast of Vancouver Island and Queen Charlotte Sound. The general current field appears to be heavily dominated by the presence of a large annual cycle in the upper part of the water column with the result that monthly averages of currents computed from different years' data, but for the same month, show considerable consistency. The presence of a southward jet just seaward of the shelf edge during the summer months is

consistent with a response of the coastal waters to upwelling by favourable winds.
 (Contact: H.J. Freeland.)

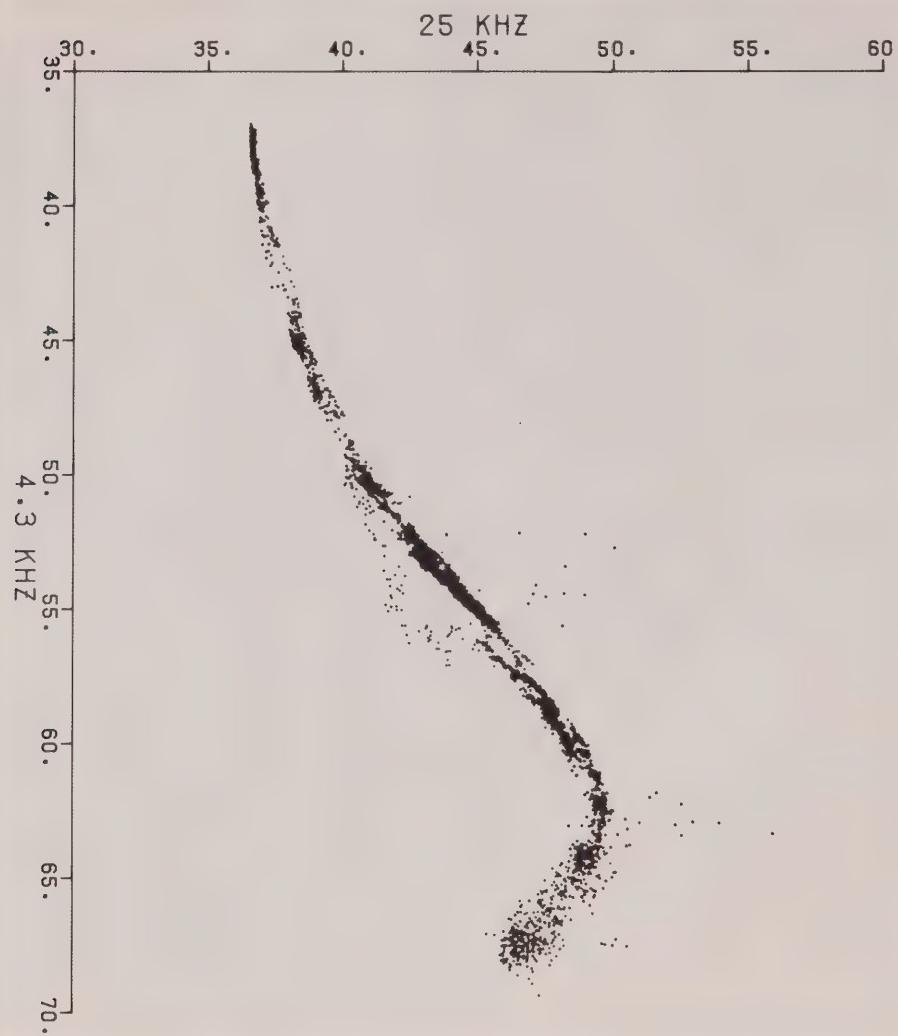


The alongshore component of flow is plotted against distance from shore off Estevan Point, half way up the west coast of Vancouver Island, for three summer months. The data clearly show the presence of a southward flowing jet seaward of the shelf edge, and a nearshore northward flowing jet, the Vancouver Island Coastal Current. The former jet is observed to be only a summer feature, whereas the latter is present year round. A simple vorticity balance theory for the response of the water on a continental shelf and slope to upwelling favourable winds predicts a current profile as shown in the figure by the continuous line. In particular the theory predicts that the current shape is proportional to $\frac{1}{H} \frac{dH}{dx}$ where $H(x)$ is the depth at a distance x offshore. The maximum of this function always occurs a short distance seaward of the shelf edge for any reasonable shelf/slope profile. The theory fails to account for the current field close inshore, which is not surprising, the nearshore current is driven by coastal buoyancy sources and probably only modulated slightly by the wind systems.

IOS is participating in the Australian Coastal Experiment (ACE) in an effort to determine whether the oceanography of the continental shelf is controlled by the physics of shelf waves. The experiment is an international venture with major contributions from Canada (IOS), USA (Oregon State University and Florida State University) and Australia (CSIRO and the Royal Australian Air Force). In September, IOS personnel deployed six current meter moorings on the New South Wales Shelf and similar deployments were made by Oregon State and CSIRO. Tide gauges, deep pressure gauges, meteorological buoys and surface, satellite-tracked, drifting buoys were also deployed. The deployment period is six months and during that time CSIRO is conducting monthly CTD surveys and the RAAF is executing frequent AXBT surveys. (Contact: H.J. Freeland.)

Analysis of data from Observatory Inlet revealed new information on the internal hydraulic adjustment of flow over the sill to changing tidal speeds. The flow evolves through a sequence of modal responses, including critical flow with respect to the second internal mode, followed by a transition regime, followed then by critical flow with respect to the first internal mode. The intermediate step between first and second modes exhibits a condition, theoretically predicted but not previously observed in natural flows, known as virtual control with respect to second mode. In this state, flow over the sill crest is super-critical with a smooth hydraulic transition occurring some distance upstream of the crest and a sudden and turbulent reversion to sub-

critical flow some distance downstream. The flow was also studied with a small laboratory model. (Contact: D.M. Farmer.)



Scatter plot of acoustic noise levels measured on the sea floor in Queen Charlotte Sound at two frequencies (4.3 and 25.0 KHz). Most of the noise is generated by the action of wind on the sea surface. At higher wind speeds bubbles entrained by breaking waves scatter and absorb the sound, providing some acoustical insulation and causing the upper right hand portion of the plotted points to curve over, as the higher frequencies are suppressed. Points lying above the principal curve show the influence of noise due to precipitation; points lying below show the effects of passing ships.

Ambient noise in the ocean at higher frequencies ($>4\text{KHz}$) is being studied for its potential in the remote sensing of processes at the air-sea interface. Measurements during the summer in Queen Charlotte Sound confirmed that wind/noise relationships found in the deep ocean also apply on the continental shelf and demonstrated the possibility of separating from the signal contributions due to precipitation. However, further data collected during the winter revealed an unexpected change in spectral properties of the noise level at higher wind speeds. For winds greater than 12 ms^{-1} , noise at the higher acoustic frequencies appears to be attenuated and can actually decrease with increasing wind speed. The effect is attributed to scattering and absorption by bubbles near the ocean surface. The results can be inverted to provide both bubble population densities and size distributions. These are consistent with the few previously available estimates, but greatly extend the wind speed range for which such estimates are known. (*Contact: D.M. Farmer.*)

A range-gated Doppler sonar was used to resolve flow structure over sills. Measurements have also been made in undisturbed water, as part of a program to determine instrument sensitivity and other operational characteristics. The Doppler receiver was also incorporated in a prototype profiling device with which to test a novel approach for measuring sound speed through the refraction of narrow beams generated by a multi-element linear array. This work is being carried out with graduate students from the University of Victoria and the profiling study is being supported by NOAA. (*Contact: D.M. Farmer.*)

Forward scatter of sound over short path lengths is being explored for its potential for remote sensing of flow speed and microstructure across tidal channels. An experiment was carried out in Sansum Narrows using a single projector and three receiver elements. Simultaneous velocity measurements as well as temperature microstructure measurements were obtained for comparison with the acoustic data. This project is designed to test the viability of wave propagation theory in inhomogeneous media for inverting both phase and amplitude scintillations to recover horizontal profiles of flow speed and other properties of the flow in coastal waters. This work is being done jointly with the Wave Propagation Laboratory in Boulder. (*Contact: D.M. Farmer.*)

A prototype microscale profiler, FLY, was built and tested in conjunction with Tidal and Current Surveys. The profiler carries instruments to measure pressure, temperature and dissipation-scale velocity shear and is adaptable for very near-bottom profiling. (*Contact: W.R. Crawford, A.E. Gargett.*)

A critical evaluation was made of various methods used to derive the vertical eddy diffusivity K_V assumed to characterize turbulent transport of mass across isopycnals in a stratified fluid. The most reliable estimates suggest that, for systems mixed by internal waves, $K_V = a_0 N^{-1}$ is an improvement on the standard assumption of constant K_V . The parameter a_0 is a function of particular systems; for the ocean, a value of $a_0 \sim 1 \times 10^{-3} \text{ cm}^2 \text{s}^{-2}$ can be derived. (*Contact: A.E. Gargett.*)

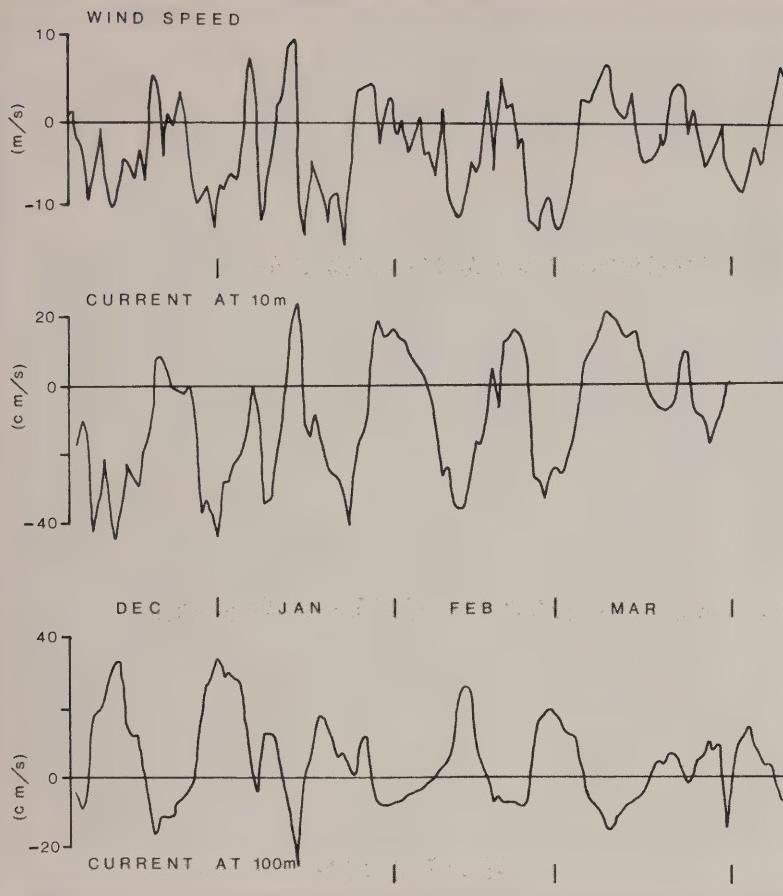
Analysis of Alice Arm and Observatory Inlet data showed that the deep water exchange in Alice Arm was more intense in the winter of 1981-1982 than in the

winter of 1982-1983. Deep water exchange in Alice Arm occurred between late December 1981 and early April 1982 when there was a seasonal increase in the density of the near surface waters because of reduced run-off and winter cooling. During this period, individual renewal events were observed and it appears that the timing and strength of these is controlled by the density fluctuation in Observatory Inlet. In Observatory Inlet energetic low frequency currents were observed at 10 m and 100 m that were 180° out of phase. These low frequency currents (\sim 20 day period) are coherent with the local wind, with 50-70% of their variance accounted for by the wind. Coherent with the low frequency currents are the density fluctuations that appear to control the timing of the deep water renewal events in Alice Arm. (Contact: D.J. Stucchi.)

The microscale profiler FLY was used during two cruises to Queen Charlotte sound during 1983. The large ring protected probes from the bottom during studies of tidal mixing over shallow banks.



Tidal height, CTD and current velocity data are being used to examine the tidally-driven circulation in Observatory Inlet and Alice Arm. Analysis of the tidal height data has shown that there are large seasonal variations in the power withdrawn from the barotropic tide. A simple theoretical model and the current velocity data show that much of this power is being fed into a progressive, internal tide. This internal tide is generated by the interaction of the barotropic tide with the sill of Observatory Inlet. The power in the internal tide varies seasonally because of seasonal variations in the stratification of the water column. The barotropic tide also drives highly non-linear, internal motions in the vicinity of the sill. These motions are more rigorous during spring tides than neap tides and so more energy is available for mixing during spring. Because of this, a significant baroclinic current occurs at the beat frequency of the M_2 and S_2 tides. (Contact: M.W. Stacey.)



Low passed, along channel winds and currents in Observatory Inlet (positive values are up inlet) during the winter of 1981/82. The resemblance between wind and currents is apparent.

Frozen Sea Research Group

During 1983, the scientific effort of the Frozen Sea Research Group was directed towards describing and understanding those physical processes which accomplish the transport and diffusion of water properties within the upper 1000 m of the ocean in the Arctic and across the ocean-ice and ocean-atmosphere interfaces. The major geographic focus areas were the channels between the islands in the Canadian Arctic archipelago and portions of the continental shelf which border on the Arctic Ocean and the Beaufort Sea. Some work was also carried out in the deeper waters of the Arctic Ocean overlying the Alpha Ridge. In support of these projects considerable effort was directed towards the testing and development of equipment and instrumentation. The investigational works were closely interrelated and new

insights gained in one area frequently had a profound influence on progress in another.

Substantial additional financial and personnel support was made available by the Office of Energy Research and Development (OERD) and by Transport Research and Development to enhance the level of oceanographic knowledge and understanding prior to hydrocarbon development and transportation within the Beaufort Sea and Northwest Passage.

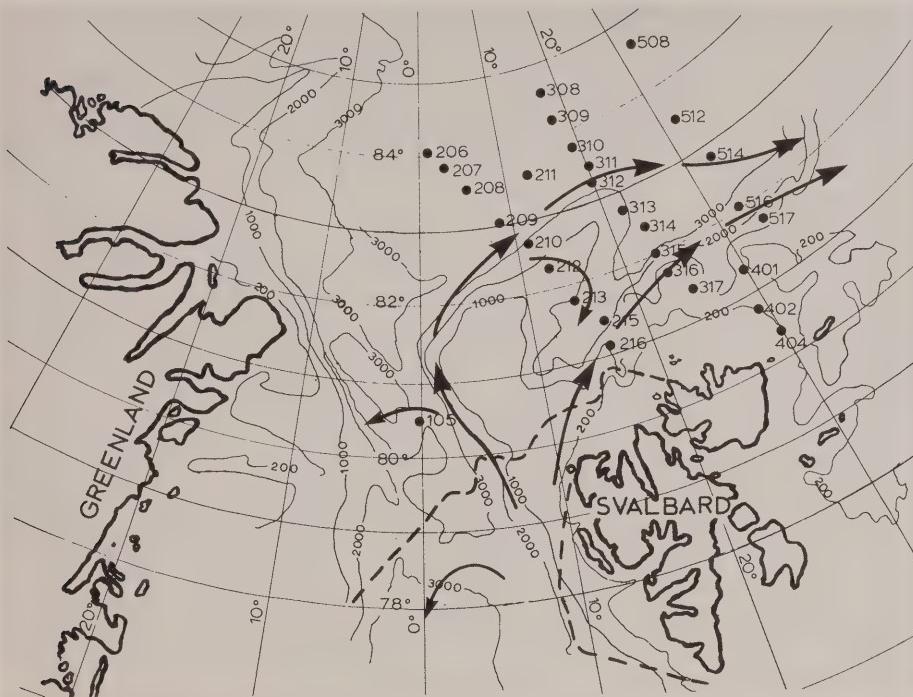
Interpretation of the early winter hydrographic data from the Beaufort Sea in 1979 was completed with the publication of a journal article and a technical report. Principal findings were a haline circulation on the Mackenzie Shelf and Slope driven by wintertime freezing, a systematic modification of Atlantic water temperatures near the continental margin and an improved knowledge of ocean circulation in this area. Interpretation of the more detailed observations of the haline circulation made in the spring of 1981 is continuing. A strong haline front was identified on the outer shelf, and a strong undercurrent over the outer shelf and upper slope of both the Alaskan and Mackenzie shelves was delineated. There is evidence that this undercurrent penetrates a significant distance into the archipelago. Data have been shared with the United States Coast Guard and with the Atmospheric Environment Service who are co-participants in the project. (*Contact: H. Melling.*)

A second year of field data were collected providing water level, water structure and current velocity information in and adjacent to the NW Passage. Analysis to date has provided information on surface current patterns in Prince of Wales Strait and Viscount Melville Sound and an understanding of the upward flux of heat from the Atlantic water in the region which warms the subsurface waters of the Northwest Passage which, when brought to the surface over sills in the central archipelago, contributed to the formation of polynyas or of thin unstable sea-ice covers. Water level data collected over 15 months in Prince of Wales Strait will permit determination of integrated channel flow from cross-channel pressure differences. (*Contact: R. Lake, H. Melling.*)

A program of water height measurement along the Canadian Arctic continental shelf was continued in cooperation with the Tidal and Current Surveys of the Canadian Hydrographic Service. Water pressure gauges were replaced at Mould Bay, Isaacsen, Audhild Bay and Pond Inlet to supplement existing permanent gauge sites and so to provide a record of pressure changes from the Beaufort Sea to the north coast of Ellesmere Island and across the archipelago. It is hoped that pressure information from other points in the Arctic Ocean will be acquired and the propagation of non-tidal water height anomalies will be investigated. These studies will be supplemented during 1984 by programs involving the deployment of current meter and CT chain moorings. The overall goal is to acquire a better understanding of water movement and water mass changes within the archipelago throughout the year. (*Contact: E.L. Lewis.*)

The analysis of data acquired north and east of Spitsbergen in the spring of 1981 is now complete. In this area the comparatively warm waters of the Western Spitsbergen Current enter the Arctic Ocean and details of this entry and subsequent

mixing are of great importance to studies of Arctic oceanography. It was found that the warm water flowed in two filaments, one next to the north coast of Spitsbergen and the other about 300 km to the north following the edge of the continental slope. Heat was lost from the West Spitsbergen Current above these filaments through the ice into the atmosphere, and generally by interweaving with colder waters to the north.



The largest island in the Svalbard group is named West Spitsbergen and the heavy arrowed lines show the bifilamentary trajectory of the warm West Spitsbergen current as it enters the Arctic Ocean from the Atlantic. This current is the major oceanic heat source to the Arctic Ocean and Fram Strait, the channel between Greenland and Svalbard, shown above, is the only deep water connection between the Arctic Ocean and adjacent seas. The depth contours are shown. On the western side of the Strait, next to Greenland, the cold East Greenland current carries Arctic Pack Ice southward down the coast. This ice stream extends to the southern tip of Greenland, Cape Farewell, and then continues to follow the coast as it turns northwards to form the eastern boundary of the Labrador Sea. The sites of our oceanographic stations are shown as numbered dots on the figure.

One outcome of these studies was the observation that near-surface waters in a broken and ridged ice field were normally slightly supercooled. This results from the non-uniform ice thickness and the variation of freezing point with pressure. The phenomenon has been noted previously in conjunction with floating ice shelves, particularly those in Antarctica where, 500 m below sea level, the freezing temperature is about 0.4°C below that of the same water at the surface. Any process

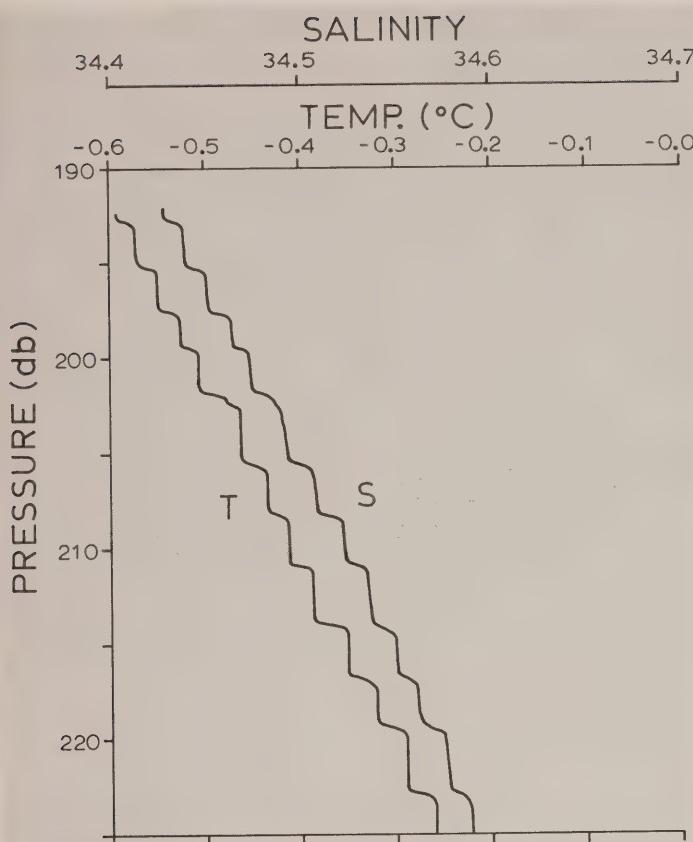
then causing vertical movement of such water enables it to become supercooled as the pressure is relieved and forms a potential heat sink for freezing. The same process occurs between the leads and ice keels of the Arctic Ocean but on a much smaller scale; it is discussed in Lewis and Perkin (1983). (*Contact: E.L. Lewis, R. Perkin.*)

Preliminary analysis of data acquired in the McMurdo Sound area of Antarctica in the fall of 1982 is now complete but more is planned for 1984. It is the most extensive survey of its type to date. In the spring of 1983 advantage was taken of the establishment of the CESAR camp over the Alpha Ridge in the Arctic Ocean and CTD surveys were run northward from the coast of Ellesmere and Axel Heiberg Islands out to the CESAR camp with an additional section joining them at the CESAR latitude running from the Makarov Basin to the Canada Basin. Of note is the extensive double diffusion indicated by a step structure in the Arctic thermocline which gradually becomes more diffuse near the coast. (*Contact: R. Perkin, E.L. Lewis.*)

Routine hydrographic profiling by CTD has provided numerous examples of thermohaline layering reminiscent of double-diffusive convection in the Beaufort Sea and Arctic Ocean. Weak gradients in these structures permit direct computation of the diffusive fluxes of heat and salt. These are found to scale well with laboratory data on similar structures. In the Beaufort Sea, the results indicate that very low heat fluxes are achieved by these processes (of the order of 0.02 W/m^2 !), but that higher fluxes of a double-diffusive nature are encountered closer to the area of Atlantic-water inflow to the Arctic Ocean. (*Contact: H. Melling, D.R. Topham.*)

The OERD Ice/Ocean Dynamics Program began in 1983. The goal of this program is an improved understanding of the dynamics of the momentum transfer between the ocean and pack ice in ice-covered waters, and of those aspects of the dynamical oceanography of the Beaufort Sea pertinent to the short-term prediction of the sea-ice motion in this area. Attainment of this goal will provide a sound physical basis for the refinement of ice-motion prediction models used operationally in the Beaufort Sea. The region of prime interest is south of 73.5°N between 124°W and 141°W . The design of this program is still incomplete but an important aspect of the interaction is the direct transfer of momentum at the ice-water interface, usually parameterized as a drag coefficient. Since a major unknown is the drag contribution from downward projecting ice keels, this aspect has been selected for detailed study. Of particular interest is the interaction between keel-generated lee waves and flow separation, as it is the latter which is thought to make a major contribution to the overall keel drag. Numerical experiments are being designed to make use of data assimilation techniques to investigate the sensitivity of model predictions to input parameters and optimal data collection schemes for predictive use. (*Contact: D.R. Topham.*)

Preliminary qualitative results were obtained from a laboratory simulation of the circulation patterns generated by a salt flux imposed on the surface of a tank with a sloping bottom when the convective mixing penetrates the full depth of the tank. This study is relevant to circulation produced by sea-ice growth over the extensive shelves of the Arctic Ocean. Shadowgraph and dye studies reveal a thin density current along the sloping bottom, and that the return flows generate significant velocity shears throughout the depth of the "mixed" layer. (*Contact: D.R. Topham.*)

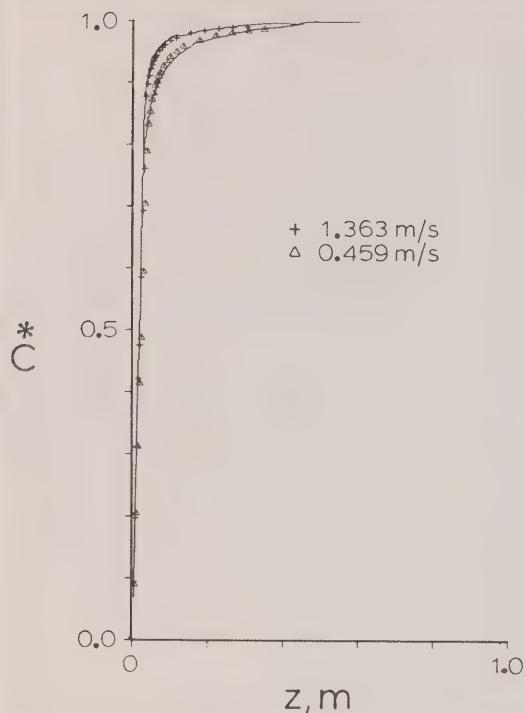


Stepped profiles of temperature and salinity at the bottom of the Arctic Ocean thermocline. The steps are evidence of double diffusive processes effecting the transport of heat and salt. Each step is composed of a comparatively well mixed layer of water separated by a sharp gradient from its neighbour, a form of profile resulting from the 100:1 difference between the diffusion coefficients for heat and salt respectively at a molecular scale. Double-diffusion in the ocean is often obscured by other, more energetic, turbulent mixing processes but in the central Arctic Ocean, which is naturally quiet and is isolated from the wind by the ice cover, the steps can develop fully. These data were taken near the CESAR camp at $83^{\circ} 33'N$ $88^{\circ} 50'W$ during April 1983.

A computer-based study of thermal diffusion in sea-ice covers was undertaken to investigate the observational requirements for the determination of vertical heat fluxes in sea-ice from ice temperature measurements. It was concluded that while existing measurement technology is probably adequate for the task, the necessary array complexity rules out the technique as a contender for simple vertical heat-flux measurement. (Contact: H. Melling.)

A general analysis of the conductivity cell response of CTD instruments was carried out in which the necessary conditions for the existence of a linear transfer function are established and are shown to be satisfied in the case of salinity changes but not that of temperature changes. Detailed response characteristics were calculated for both the Guildline and Neil Brown instruments. The calculations cover a range of instrument fall speeds. A paper on the transient behavior of conductivity sensors has been prepared for publication. A contract has been let to the Applied Physics Laboratory of the University of Washington to determine the response of the Guildline Mk IV temperature and conductivity sensors. In the case of the C-cell it is hoped to determine separately the response to salinity and to temperature and to

confirm the non-linear behavior expected to arise from diffusion effects. (Contact: D. Topham, R. Perkin.)



Response of conductivity cells used as sensors on oceanographic instruments. Shown is a comparison between the computed step response of the 3 cm cell used on a Neil Brown conductivity-temperature-depth fish and the measured response given by Gregg et al. (1982) at 0.459 m/s and 1.363 m/s lowering rates. The symbols denote computed response and the lines measured response. C star is the normalized conductivity and Z is the distance travelled by the probe.

Systematic errors in the Guildline CTD due to leakage, temperature cycling, etc. and the electronic performance of both analog and digital system components were investigated, resulting in improvement in the understanding and quality of data obtained from the instrument. Results of this work have been discussed with Guildline Instruments. An advanced designed of the salinity (i.e. C/T) chain involving distributed sensor electronics and digital data transmission is being supplied by Applied Microsystems Ltd. and tested in Saanich Inlet. The accuracy of sensors is specified to provide a salinity to ± 0.02 , assuming insignificant fouling. (Contact: R. Sudar.)

Because of the absence of a commercially available water sampling bottle suitable for use on aircraft-based hydrographic surveys, a bottle of small cross-sectional area (to facilitate sampling through holes in sea ice), low thermal diffusivity (to minimize sample freezing problems) and low immersed weight (to minimize cable weight requirements) is being designed. The first requirement necessitated in-line sealing caps, which in turn required careful design for correct hydrodynamic performance and flushing. This part of the design is now complete. Evaluations of potential materials for the bottle and its seals are currently being undertaken, and a decision

regarding fabrication technique (moulding or machining) has yet to be made. (*Contact: H. Melling, D.R. Topham.*)

A rigid current meter mooring was developed for Arctic areas where the horizontal component of the earth's magnetic field is inadequate to give a directional reference. It was deployed in Austin Channel during the spring of 1983. Several tests of rigidity and a trial mooring with both conventional and 'Arctic' current meters was deployed in Satellite Channel on the west coast. At speeds of one knot direction held to ± 5 degrees or better over a 38 metre length. The orientation of the mooring on the seafloor is determined by uncaging a gyro after the mooring is in place. The gyro is then returned to the surface and read. (*Contact: S. Moorhouse.*)

The results of careful laboratory measurements on the drift characteristics and stability of Paroscientific pressure transducers which are commonly used in sea-floor tide gauges are being investigated. Preliminary results suggest that for the 30 db-range sensors, calibration drift over 1 year does not exceed 1 mb, and that the drift is predictable and thus correctable to within a few tenths of a millibar. This order of accuracy is adequate for the estimation of flows in channels from cross-channel pressure differences. (*Contact: H. Melling, W.R. Buckingham.*)

During the past several years considerable attention has been paid to the Fram Strait Project, proposed by the Comité Arctic International as a major international cooperative study in polar oceanography. Regrettably and after considerable efforts to raise the necessary funds, this initiative has been abandoned and the Management Group disbanded, a victim of changed economic circumstances, particularly in the petrochemical industries. (*Contact: E.L. Lewis.*)

Group members have also been intimately concerned with the work of international advisory organizations (e.g. SCOR Working Groups) and national committees. They have also been called upon to provide technical comment on the EIS for Beaufort Sea Development, and at public hearings.

The Group was invited to provide technical and scientific input into the Beaufort Environmental Monitoring Project (BEMP), a project initiated by the Department of Indian Affairs and Northern Development (DIAND) which strives to produce recommendations for a sound and defensible monitoring program which could potentially accompany industrial development in the Beaufort area. (*Contact: H. Melling.*)

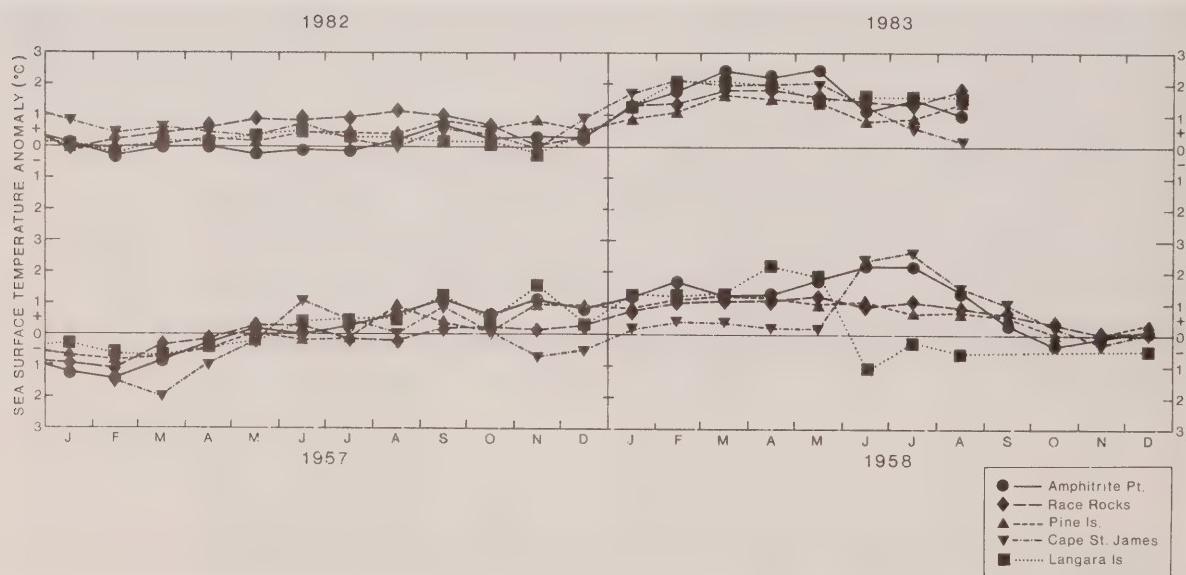
Offshore Oceanography

Current and water property measurements collected during the Coastal Oceanic Dynamics Experiment (CODE) revealed the formation of a mesoscale baroclinic eddy off the central coast of Vancouver Island in the fall of 1980. The eddy core was characterized by near-surface currents of 50 cms^{-1} , a radius of 50 km and mid-depth

isopycnal displacements of 50 m. Growth of the eddy is sustained through dynamic instability of the prevailing coastal current consisting of a southeastward wind-driven surface current and northwestward flowing California undercurrent. A study of the energetics shows that roughly 82% of the energy flux from the mean to the eddy field is via baroclinic instability and that the characteristic time scale for the eddy growth is 25 ± 10 days. (Contact: R.E. Thomson.)

In conjunction with the Australian Institute of Marine Sciences (Townsville), six months of current and temperature data were collected from Raine Island Entrance ($11^{\circ}38'$ south latitude) on the Great Barrier Reef. These data show that tidal motions lead a pronounced upwelling of cold, nutrient-rich continental shelf water on to the reef and that the seaward eddy heat flux of 0.79 ± 1.01 cal $\text{cm}^{-2}\text{s}^{-1}$ at the outer reef corresponds to onshore fluxes of nitrate, phosphate and silicate of $0.9(\pm 1.2) \times 10^{-2}$ $\text{mmol m}^{-2}\text{s}^{-1}$, $0.7(\pm 0.9) \times 10^{-3}$ $\text{mmol m}^{-2}\text{s}^{-1}$ and $0.6(\pm 0.8) \times 10^{-2}$ $\text{mmol m}^{-2}\text{s}^{-1}$ respectively. Details of the upwelling mechanism were also described. (Contact: R.E. Thomson.)

A detailed study was completed of barotropic and baroclinic continental shelf waves of diurnal period off the west coast of Vancouver Island. Results suggest that the larger amplitude shelf waves consist primarily of first mode baroclinic oscillations that are significantly modulated by seasonal variations in the prevailing alongshore current over the continental shelf and slope. (Contact: R.E. Thomson.)

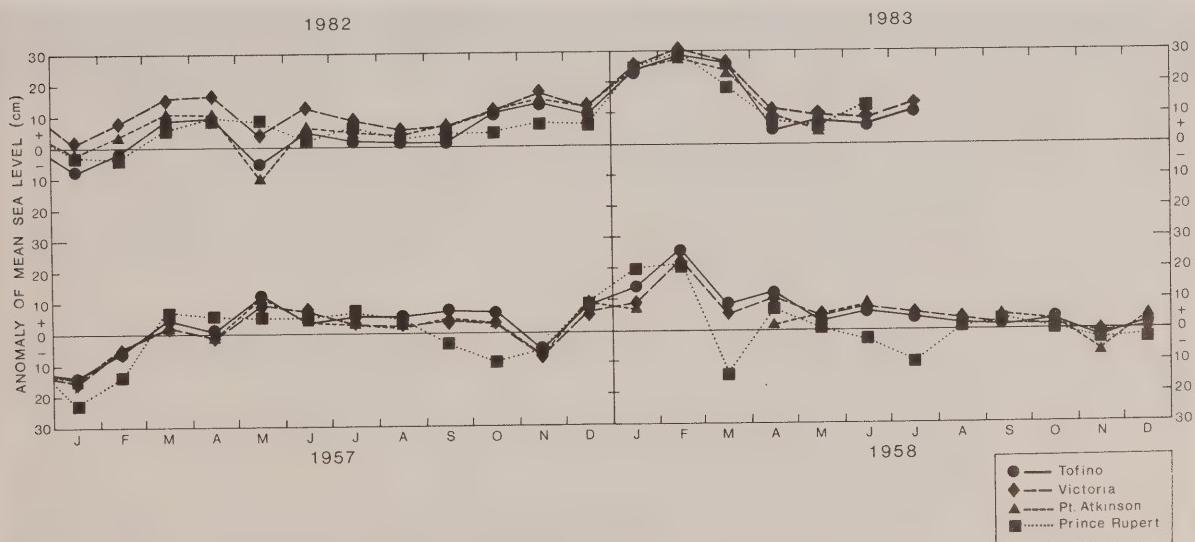


Anomaly of monthly mean sea-surface temperature ($^{\circ}\text{C}$) from exposed coastal stations: Race Rocks, Amphitrite Point, Pine Island, Cape St. James and Langara Island (south to north)—1982-1983 and 1957-1958. Anomalous warming of coastal waters occurred all along the Pacific coast of North and South America during the 1982-1983 ENSO. The largest warming occurred along the coast of northern Peru in spring-summer 1983. The anomaly here was as large as $+7^{\circ}\text{C}$, the largest ever recorded!

Winds measured over the continental shelf off Vancouver Island during the summers of 1979 and 1980 were compared with winds computed by the National Marine Fisheries Service (Monterey). It is shown that the computed winds fail to resolve transient wind patterns and that such winds are only representative of oceanic winds for time variations of longer than two days. Spectra of the observed winds suggest a $k^{-5/3}$ law behavior (k is the horizontal wave number) consistent with the existence of a mesoscale, two-dimensional, cascading enstrophy inertial range.
 (Contact: R.E. Thomson.)

The Northeast Oceanic Dynamics Experiment (NCODE) was begun in May to study the circulation and long wave propagation along the 300 km west coast of the Queen Charlotte Islands. Characterized by a narrow (5 km) continental shelf, steep slope and strong winds, this region is one of the last oceanographic frontiers of the British Columbia coast. Preliminary results for the current and satellite-tracked drogue studies reveal a complex flow pattern in this area with a coastally-trapped, clockwise eddy off Cape St. James at the southern end of the Queen Charlotte Islands and mesoscale meanders and eddies off the central portion of the Islands. There is both theoretical and observational evidence for strong bottom-trapped current oscillations over the outer slope. (Contact: R.E. Thomson.)

During 1983 two cruises along Line P and three other lines between the Canadian west coast and Station P were made; one in March and the other in August.



Anomaly of monthly mean sea level heights (cm) from representative coastal tidal stations: Victoria, Tofino, Point Atkinson (near Vancouver) and Prince Rupert (south to north) 1982-1983 and 1957-1958. Anomalous rise of mean sea level apparently occurred all along the Pacific coast of North America. (We have no data to indicate such a rise occurred along the South American coast.) It appears that the rise occurred about a month earlier at southern California shores.

The 1982-83 El Nino-Southern Oscillation (ENSO) event is now considered to be the largest global anomaly of the ocean-atmosphere system of this century. The earliest suggestion of this anomaly was the drop in atmospheric pressure in the southeast Pacific Ocean and a rise of pressure over Australia during the summer of 1982. This was followed by the weakening of the trade winds over the equatorial and tropical Pacific. By the latter part of 1982 it became evident that a major climatic anomaly was occurring. In the eastern equatorial Pacific sea-surface temperature anomalies were as large as +5°C. Along the Pacific coast of North America an anomaly of +2°C occurred off Mexico and by the early part of 1983 the development of this anomaly extended as far north as off the Pacific coast of Canada. The ENSO effect along the Canadian coast was featured by increasing sea-surface temperatures especially during December 1982 - March 1983. A corresponding rise of mean sea level occurred during the same period. A maximum anomaly of sea-surface temperatures (+2.5°C) was reached during March-May 1983 while the highest anomaly of mean sea level (25-30 cm) was reached in February.

Oceanographic data taken along Line P during March 1983 revealed that the warm water intrusion associated with the 1982-1983 ENSO was restricted to less than 250 km off the coast. Comparison with the 1957-1958 ENSO effect indicated that while the behavior of ocean water along the coast was similar, both in terms of sea surface temperature and mean sea level, the areal extent of the earlier ENSO was many times greater than the 1982-83 event. However, the magnitude in 82-83 of the anomalies along the coast appears to be greater.

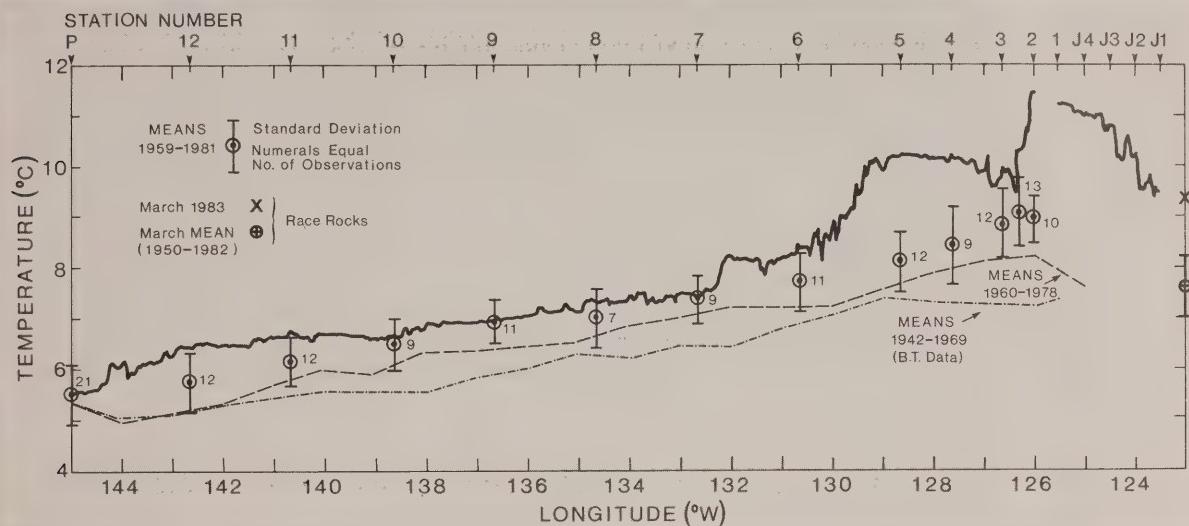
The development of the ocean climate anomaly during 1982-1983 affected the ecosystems of the coastal waters off both the North American and South American coasts. Along the California coast the rise in the anomaly of SST and mean sea level was accompanied by the appearance of *Pleuroncodes planipes* (pelagic red crab). Its previous occurrences were in 1941 and 1957-1958, which also were ENSO years. Similarly, barracuda appeared off California during 1983 as they did in 1958 and 1941. The occurrence of Pacific bonito, swordfish, green sea turtles and many sunfish off the B.C. coast is likely to be due to the ENSO effect, as it was during 1957-1958. (*Contact: S. Tabata.*)

Studies of two-dimensional turbulence included a theoretical investigation of the ability of turbulence to impress its characteristic scales upon phytoplankton concentrations, leading to patchiness and, the comparative roles of the enstrophy subrange and the large scale eddies in the relative dispersions of oceanic and atmospheric drifters. (*Contact: A.F. Bennett.*)

Inverse theory was used to estimate the efficiency of an array of seafloor-mounted pressure gauges and acoustic tomography probes for observing tides and individual interannual variations. (*Contact: A.F. Bennett.*)

An on-going upper ocean dynamics study was continued with the analysis of historical data. A ship-of-opportunity program was started in May using two ships on trans-Pacific routes. Surface temperature and salinity were recorded at one minute intervals, representing an order of 200 m spatial resolution. Recordings

showed many locations where salinity gradient was in the order of 2‰ per km and where temperature gradient was in the order of 5°C per km. On two of the trans-Pacific crossings, XCTDs were deployed. Through analysis of the time-series of such sections, it appears that the dynamics of the warm water off Vancouver Island in the summer months may be closely connected with the fresh water run-off from the Columbia River. Analysis underway will improve the description of the situation.
 (Contact: M. Miyake.)



Sea-surface temperatures along Line P (between the southern coast of B.C. and Station P). The largest anomaly of SST occurred in a band 250 km off the coast, east of Station 12.

Forecast Methods

In the course of joint three-dimensional numerical model (4 km mesh) studies with the University of Hamburg, an improved barotropic tidal calibration and simulation of tidally-induced residual currents was achieved. Attention is now being directed to improving the density-driven circulation in the model. (Contact: P.B. Crean.)

Work is continuing on the development of a buoyant spreading upper-layer model of the shallow plume formed by the tidally modulated discharge from the Fraser River spreading over denser water in Georgia Strait. Extensive field data were analyzed to show the tidal and seasonal changes in distributions of velocity, salinity and layer thickness throughout the plume. Sensitivity trials of the model have been completed

and comparison of the modelled and observed distributions are in progress. This work is being carried out under contract. (*Contact: P.B. Crean.*)

A higher resolution (2 km mesh) vertically-integrated, barotropic model of mixed tides in the overall region, including the areas between Vancouver Island and the mainland coasts of B.C. and Washington, was developed and is undergoing calibration. The model will provide data for input to an extended version of the buoyant spreading upper-layer model referred to above, as well as an improved simulation of the tidally-induced residual circulation. (*Contact: P.B. Crean.*)

The accuracy and economy of finite element methods in tidal and storm surge models was studied. Some methods were found to be competitive with explicit finite difference schemes. Further investigations have suggested accurate choices of boundary conditions, and element size and shape. External requests for the tidal analysis and prediction programs have brought the number of worldwide users to over 50. (*Contact: M.G. Foreman.*)

The concept of diffusive kinematic waves was invoked to account for the very slow travel of the 1960 Chilean earthquake tsunami on the west coast of Canada. The traditional Lagrange formula for the velocity of long gravity waves such as tsunamis is not applicable in frictionally-dominated coastal inlets and river systems. Tsunami forerunners have been explained qualitatively as lateral waves which are diffracted long waves at continental shelf edges. (*Contact: T.S. Murty.*)

The influence of ice cover on long gravity waves such as tides and storm surges was examined in Canadian waters. Study showed that a marginal ice cover damps the crests much more strongly than troughs. (*Contact: T.S. Murty.*)

At the request of various UN agencies, several papers dealing with water systems, storm surges, tides and movement of oil slicks in the Bay of Bengal, Gulf of Oman and the Arabian Gulf were prepared. (*Contact: T.S. Murty.*)

A regular grid linear finite difference model was used in conjunction with an inverse model to obtain the best possible fit to available observations of the M_2 tidal constituent to the Dixon-Hecate-Charlotte system. This work provided M_2 cotidal charts for Hecate Strait but confirmed the need for further field measurements in Dixon Entrance and the mouth of Queen Charlotte Sound. An irregular triangular grid was prepared to provide a basis for subsequent, more detailed models. (*Contact: R.F. Henry.*) A storm surge flood delineation study for Tuktoyaktuk, NWT and the town's immediate environs was undertaken on behalf of Environment Canada. The final product of this contract will be a map showing the area threatened by flooding in the event of a "100-year" storm surge. (*Contact: R.F. Henry.*)

Advice was supplied to the World Meteorological Organization on field programs required to improve the performance of storm surge prediction systems in countries bordering the Bay of Bengal. (*Contact: T.S. Murty, R.F. Henry.*)

Remote Sensing

Work continued on the fluorescence line image sensor being built for IOS to map sea surface phytoplankton concentrations. Various instrumental effects caused by the CCD imaging elements were located and largely corrected. Flight tests were conducted in December.

The image processor system was transferred from the shared 11/34 computer to a dedicated machine. The original OVAAC-8 software was supplemented by programs to display and rectify visible and thermal imagery from the NOAA weather satellites and water colour (phytoplankton pigment) imagery from the Coastal Zone Color Scanner on Nimbus 7. A collection of imagery of the B.C. coast is being rectified and analyzed in support of physical and biological studies of Hecate Strait, Dixon Entrance and the west coast of Vancouver Island. Imagery of the east coast of Canada and of the Beaufort Sea is also being collected.

An airborne water-colour survey in the western Arctic, off the Mackenzie Delta, was carried out under contract in conjunction with two Dome Petroleum whale surveys. The IOS 256-channel spectrometer was flown on both operations, in August and September, each involving some 20 flight lines extending 90 km north from the coast. The project, funded through DSS, aims to compare whale distributions with silt and phytoplankton distributions deduced from the water colour observations.

Analysis of data collected in international programs continued, and plans were made for future cooperative ventures using the fluorescence line imager in 1985-86.
(Contact: J.F.R. Gower.)

Computing Services

A Sperry DCP/20 front-end communication processor was installed during April 1983 to replace the 25-year-old CTMC communication controller. This interface to the Sperry 1100 mainframe will allow higher speed computer graphics and protocol flow control (XON/XOFF) to intelligent devices. Although not fully operational by year-end, operational status was anticipated by January 1984. In spite of the difficulties experienced with installation, it is expected to fulfil its design goal of providing a cost-effective growth capability for communications with the mainframe. Furthermore, it is supported by new software development by Sperry, whereas the old CTMC subsystem is not.

The Datacom network was also enhanced during 1983 by the replacement of 4 BC Tel 300 bps, dial-in modems with Microcom 300/1200 bps modems. These new modems have the additional ability to provide a fully error-corrected telephone link, provided the calling terminal also uses a Microcom device. For off-site users, this

means the communications quality via dial-up telephone lines can now be as good as on-site, direct communication.

The DATAPAC usage via the IOS Datacom network continued to expand during 1983. Whereas in the past most traffic was incoming, during 1983 more applications were initiated using outgoing calls on DATAPAC. For example, access to remote electronic mail systems and remote databases was established.

In March 1983, a small, Hewlett-Packard flat-bed plotter was acquired. Although used during the remainder of 1983 by the Ocean Information section, plans are to interface this plotter to the mainframe for access by all interested computer users during 1984.

Just before the end of the year, level 10R1A of the FORTRAN compiler, Sperry's ANSI '77 implementation, was installed. Considerable work was necessary to convert software libraries to this level, as certain, non-compatible changes were required to implement ANSI '77 features and conventions.

Eleven personal and desktop computers were introduced throughout the Institute. The trend is anticipated to continue as this technology matures. For certain types of applications, such small, dedicated processors are more cost-effective than larger, shared systems. (*Contact: R.E. Johns.*)

Ocean Chemistry

The major objective of the Ocean Chemistry Division is to provide expertise, advice and a scientific perspective on both short-term and long-term problems associated with the chemical aspect of the ocean environment through both monitoring and research activities. Five areas are of prime concern: ocean pollution, ocean climate, ocean fluxes, ocean circulation and ocean productivity. The major effort is directed towards basic understanding of the long-term consequence of anthropogenic manipulation of the natural environment, but a balance is also struck by studying the short-term environmental impacts of societal intrusion.

Alice Arm/Amax Studies

This program, to fulfil the requirement for baseline knowledge and understanding of chemical processes affecting the distribution of tailings into the fjord, was continued in 1983. There are three areas of interest: sea water chemistry, pore waters and sedimentary processes.

A cruise was conducted in July to study the dissolved and particulate mercury in the water column of Alice Arm, using a semi-automated, gold-bead technique. Analysis continued of lead isotopic ratios in soluble and total lead samples from an October 1982 cruise by clean laboratory/mass spectrometric method for tracing and assessing the tailings-derived lead in Alice Arm. (Contact: C.S. Wong.)

Time-series measurements of pore waters in Alice Arm continued. Metal availabilities from tailings and from natural sediments were also studied using an HCl-leaching approach. The study indicated, as an example, that zinc in tailings was only 10% of the total while in natural sediments was about 50%. (Contact: J.A.J. Thompson.)

Sediment trap material and tailings were analyzed for metals, organic carbon, chlorophyll-a, microscopy and X-ray diffraction assay, and data were compiled into a 3-part data report on chemical oceanography, covering particulates, sediment trapping and coring. (Contact: R.W. Macdonald.)

Metal-binding protein (MBP) and total metal contents in the tissues of King Crabs from the fjord were also analyzed at the request of Fisheries Management. (Contact: J.A.J. Thompson.)

Coastal Pollution

The objective of this program is to understand organometallic species and the detoxification mechanism of metal-protein complexes (metallothioneins) in marine organisms and their transformation mechanisms in the marine environment so that environmental significance of "pollutants" can be assessed in a meaningful way.

Major effort was expended on the metal binding protein (MBP) study, particularly on methodology development. Further development of the polarographic assay technique, by using a cell temperature of 5-7°C and a modification of the Brdicka electrolyte, pushed the detection limits to less than $1\text{ }\mu\text{g MBP L}^{-1}$. Improvements by removing interfering material by denaturation, using alcohol or heat, led to better estimates of MBP in two local clam species, *Protothaca staminea* and *Venerupis tenerima*. Denaturation removes half the signal contributors. This approach is also being applied to the assaying of MBP in oyster tissues from areas around Crofton, B.C. A comparison was made of this technique with the immunoassay method for MBP used in Batelle NW Laboratories at Sequim, Washington. (Contact: J.A.J. Thompson, B.I. Imber, S.L. Ward.)

A project was also initiated to study metal-binding proteins in organisms collected from the Juan de Fuca Ridge hydrothermal vents in cooperation with the University of Victoria. (Contact: J.A.J. Thompson, V. Tunnicliffe.)

Arsenic speciation and budget in Rupert Inlet and the Alice Arm area was studied

as a cooperative project with Royal Roads Military College with an enlarged sampling regime including plankton and riverine material. (*Contact: J.A.J. Thompson, K. Reimer.*)

Hydrocarbons and Pesticides

The objective of the hydrocarbons and pesticides program is to advance the knowledge of the occurrence, pathways and fate of hydrocarbons (natural, petroleum-based, chlorinated and pesticidal) in the marine environment.

The emphasis of the 1983 program was methodology development for the assay of polycyclic aromatic hydrocarbons (PAHs) in mussel tissues and the assay of crude oil and radioactivity-labelled hydrocarbon to study the fate and pathways of Prudhoe Bay crude in the ocean enclosed experiment described under SEAFLUXES.

The suitability of freeze-dry and Soxhlet extraction methods for quantifying hydrocarbons in mussel tissues using gas chromatograph/mass spectrometer/computer system (GC/MS/DS) was established experimentally.

Three experimental techniques were developed and used in the SEAFLUXES crude oil/dispersant experiment. These were: n-($1-^{14}\text{C}$) hexadecane labelling of crude oil, *in situ* fluorometry and epifluorescence microscopy. The *in situ* fluorometry indicated that the bulk of the oil mixed with dispersant, Corexit 9527, resulted in a form filterable by $1-\mu\text{m}$ filters and associated with detritus matter. The epifluorescence microscopic technique for enumeration of bacteria in the degradation experiment was found to be applicable to visual examination of oil droplets as small as $0.1 \mu\text{m}$ or less. (*Contact: W.J. Cretney, J. Li.*)

Fjord and Arctic Chemistry

The objective of the program is to gain new knowledge of the environmental factors controlling the circulation and sedimentation in B.C. fjords and in the western Arctic. Such new knowledge will contribute to environmental impact statements and assessment of pollutant effects associated with industrial development.

Field activities were devoted to the Alice Arm fjord system as described under Amax. Lead-210 dating technique was applied to sediment cores from seismically well-characterized sites in the Kitimat fjord system and to cores taken in the Strait of Georgia to study anthropogenic vs. natural inputs of metals into the marine sediments. (*Contact: R.W. Macdonald.*)

Compilation of existing chemical data relating to the Beaufort Sea and N.W.

Passage, giving "best estimates" of budget and fluxes of hydrocarbons, metals and nutrients, was completed in conjunction with Ocean Information Division. Natural inputs were estimated to be comparable to the magnitude of projected wastes from oil exploration up to the year 2000. Ocean Chemistry Division also played an active advisory role in 1983, such as by preparing a document on environmentally-acceptable levels of metals in drilling products and by reviewing the Environmental Impact Statement for Beaufort Sea development. (*Contact: R.W. Macdonald, W.J. Cretney.*)

Ocean Dumping

Quality control of the chemical analysis of metals in sediments is a priority in the management of the ocean dumping permit system. A laboratory performance check was designed. Advice was provided relating to the disposal of dredged material at B.C. Place in Vancouver, the disposal of Amax mine tailings, the monitoring of Arctic mine tailings and the U.S. Borax project in Boca de Quadra, Alaska. (*Contact: C.S. Wong, J.A.J. Thompson, R.W. Macdonald.*)

Ocean Flux

Ocean flux experiments were carried out under two international cooperative programs: SEAFLUXES and PARFLUX.



*Launch day in Saanich Inlet
for the SEAFLUXES program*

With funding assistance from the International Development Research Centre (IDRC), the SEAFLUXES program involved a cooperative study at Patricia Bay with participants from Shandong College of Oceanology, the 3rd Institute of the Chinese National Bureau of Oceanography, the Department of Oceanography at U.B.C. and IOS. The study investigated the pathways and fate of Prudhoe Bay crude oil premixed with a chemical dispersant, Corexit 9527, and the biological effects of the dispersed oil and the dispersant alone on the planktonic and bacterial communities. A radioactive tracer, n-(¹⁴C) hexadecane, was added in minute quantity to label the crude oil. The total oil concentration decreased to one-tenth of the initial addition in 10 days. About 70 percent of the ¹⁴C-n-hexadecane was degraded after 9 days. The epifluorescence work indicated that the bacteria elaborate some material that coats the oil. At levels close to 10 mg L⁻¹ of the crude oil, plankton growth was severely limited. (*Contact: C.S. Wong.*)

Consultations took place with representatives of IDRC, U.B.C. and the Chinese agencies involved to draft a three-year proposal for Canada/China cooperation relating to the Marine Ecosystem Enclosed Experiment. (*Contact: C.S. Wong.*)

Another international, cooperative program, PARFLUX, involving Woods Hole Oceanographic Institution and IOS, yielded exciting results. Two cruises, one in the spring and the other in the fall, were conducted to retrieve and relaunch the automated moored sediment traps at depths of 1000 m and 3800 m, as well as a large system at 3900 m for natural radiocarbon study. Three seasonal peaks of particulate flux into deep ocean were observed in the time-series; in May, August and October. A change of an order of magnitude was evident between the low and high flux season, implying that the existing "snapshot" approach by flux investigators could not obtain a quantitative picture revealed by the time-series approach. The flux rate was also found to be of the order of 200 m day⁻¹ for particles; about 2-3 times higher than what was accepted in the past. (*Contact: C.S. Wong.*)

Marine Carbon Research Centre

The Centre, now in its fifth year, is focussing on the marine aspects of the global carbon dioxide (CO₂) cycle by conducting research, monitoring and modelling activities. The recent controversy over the U.S. Environmental Protection Agency's report on the greenhouse effect of CO₂ and the environmental consequences, coupled with a caution from the U.S. National Academy of Science, brought attention again to the lack of understanding of the crucial mechanisms of the ocean's capacity to absorb atmospheric CO₂. Signals of climate warming are vague at present, masked by background noise of natural cycles. However, they do indicate a possible increase of 0.1-0.5°C per decade, a much clearer signal by the year 2000 and a possible warming of 3±1.5°C due to future CO₂ doubling with more dramatic heating of up to 2-3 times the global average rise in polar regions, including the Canadian Arctic.



A sediment trap being deployed from
CSS Parizeau in October 1983.

Oceanic CO₂ monitoring is an essential tool in recognizing the first signals of oceanic CO₂ increase and in establishing the secular increase and long-term variability. The Centre took a lead role in conducting the first meeting of working group-75 on oceanic CO₂ monitoring of the Scientific Committee on Oceanic Research (SCOR). The meeting at IUGG in Hamburg, F.R. Germany was called to map out a global strategy, to define the precision of measurements required for CO₂ signals and to review various national capabilities for international cooperation. The oceanic CO₂ monitoring program at IOS continued to use three types of platforms: ships-of-opportunity, research cruises along Line P and the Cape St. James lighthouse. CO₂ time-series, oceanographic properties and productivity data for research and modelling purposes were provided by 2 ships-of-opportunity, the *Canada Ace*, between Tokyo and Richmond, B.C. and the *Lillooet* between Sydney, Australia; Noumea, New Caledonia and Richmond, B.C. The ships-of-opportunity program was assisted by funds from the Office of Energy R&D of the Department of Energy, Mines and Resources. This included development of a shipboard automated gas chromatograph system for atmospheric and oceanic CO₂ and the testing of the system on the *Lillooet* by IOS personnel. While on board IOS personnel also conducted work on continuous chlorophyll-a, conductivity-temperature sensing and nutrient sampling. (Contact: C.S. Wong.)

Research and modelling activities in 1983 were concentrated on working up atmospheric CO₂ data from Ocean Station P, Alert and Sable Island to establish the trend of atmospheric CO₂ increase, characteristics of the seasonal cycle and long-term natural variation. The data set has revealed a long-term atmospheric CO₂ growth rate of about 1.4 ppmv year⁻¹, with slight dips in the spline curves in 1976

and 1979 possibly due to transient variables such as surface sea temperature and the onset of El Nino. These time-series were also de-trended by removal of components of fossil fuel CO₂ function and seasonal cycle sinusoidal function to establish natural variability with the aim of constructing a diagnostic model of Canadian atmospheric CO₂ to study the relationship of sources and sinks, i.e. the Canadian land forest and Arctic and ocean CO₂ reservoirs. (*Contact: C.S. Wong, Y. Chan.*)



Ocean Ecology

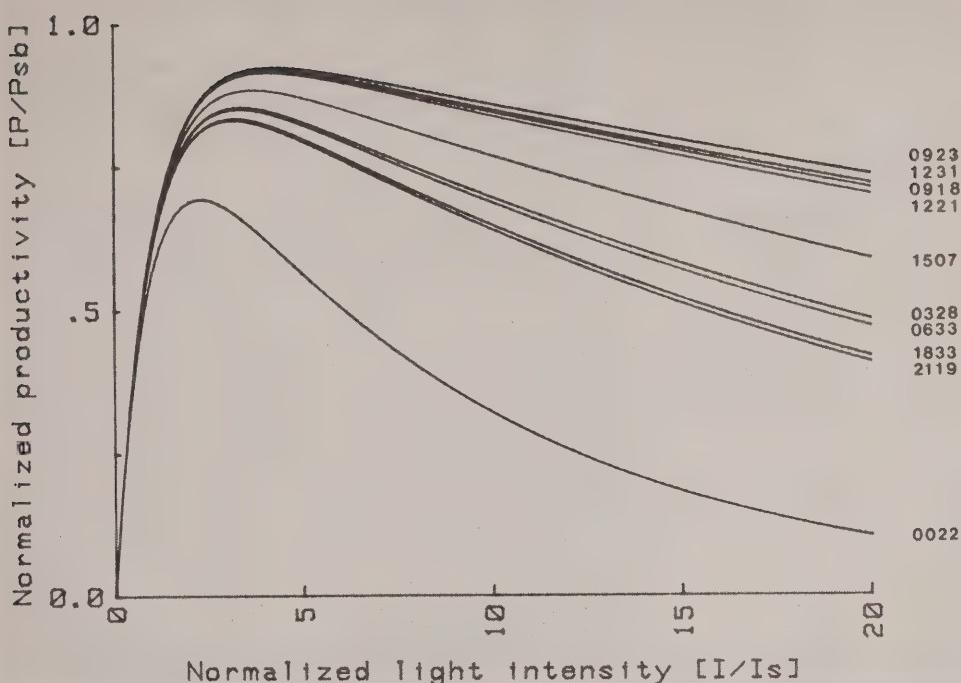


Plankton

In 1983 a study was initiated of the plankton ecosystems in Hecate Strait and Queen Charlotte Sound, an area where the biological oceanography is largely unknown. On a July cruise, high concentrations of phytoplankton and zooplankton were found over Cook Bank, at the north end of Vancouver Island. Data were highly variable with little pockets of low salinity water and with a strong physical and biological front in Queen Charlotte Strait separating stratified waters to the north from waters completely mixed from top to bottom by strong tidal currents in the narrow channels to the south. The shallow banks to the east of the Queen Charlotte Islands, important breeding grounds for many species of fish during late winter and spring, were thought to be barren of nutrients and phytoplankton during summer. However, a layer of phytoplankton living at a depth of about 20 metres that had escaped detection by previous near surface sampling from ships of opportunity was found. The finding is also noteworthy because it was thought that tidal mixing in this area would be so vigorous that phytoplankton would be evenly distributed from top to bottom. Apparently, fresh water input to the region is sufficient to supply a near surface layer of low salinity water that resists complete mixing by tidal currents. (*Contact: K. Denman, D. Mackas.*)

To answer questions that arise from the findings of biogeographical studies, such as the one outlined above, effort was focussed on studying certain individual processes in greater detail. From Ocean Ecology's four year field program off the southwest coast of Vancouver Island, the relationships between sample-to-sample resemblance and spatial separation for several different types of data (e.g. physical and chemical data, plankton biomass, the relative abundances of various species) was examined. Community structure, of both phytoplankton and zooplankton, was found to be similar over larger horizontal distances than total biomass concentration. The physical variables (temperature, salinity, and dynamic height) have a maximum dissimilarity around 30 kilometres, consistent with what one would find from random sampling of waves or eddies with scales of about 60 kilometres. This analysis will be extended to satellite imagery for the same areas. (*Contact: D. Mackas, K. Denman.*)

83-02 Drogue series [P-01 to P-10]



Results from a 24-hour productivity versus light intensity ($P(I)$) experiment, illustrating diurnal variation in $P(I)$ parameters. Note the increase in maximum photosynthetic rate and decrease in photoinhibition during the daytime hours. Sampling times (to the right of fitted curves) are in Local Apparent (solar) Time.

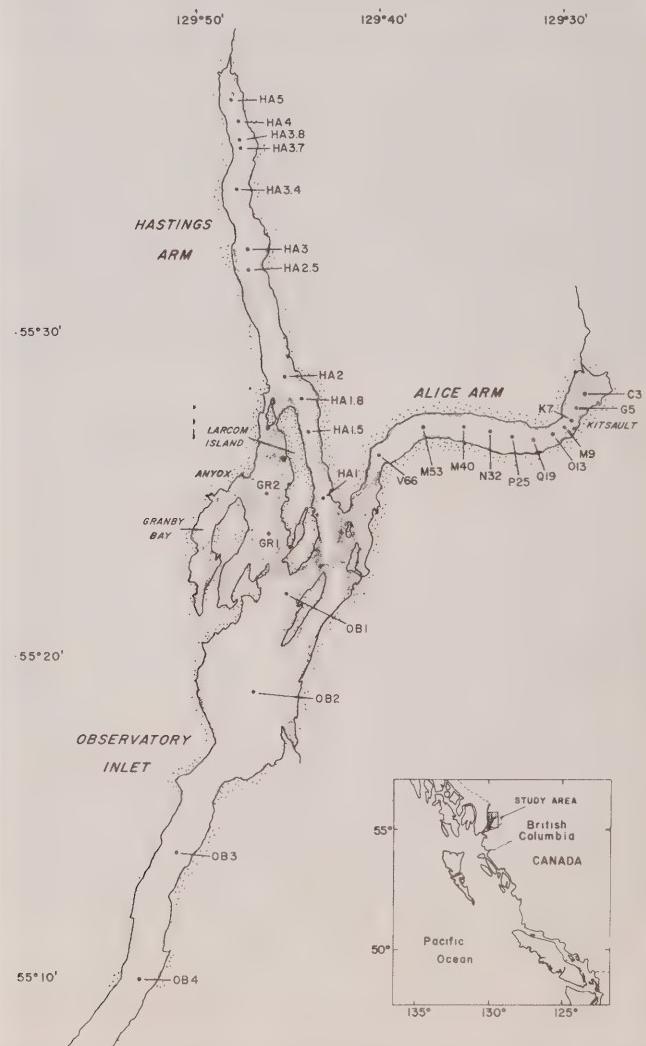
To determine spatial changes in the photosynthetic rates of phytoplankton, the extent of the daily variations in these areas must be known. Accordingly, field experiments to investigate the response of natural populations of phytoplankton to varying light were performed on two cruises. Experiments involving repeated sampling of populations over 24-hour periods were carried out in Hecate and Georgia Straits and in Saanich Inlet. These experiments provided information on the daily variation in photosynthetic parameters defining the maximum light-saturated rate of photosynthesis, the rate of photochemical reactions, and susceptibility to photoinhibition. In addition to evaluating daily cycles in these variables, the results will also provide supporting data for models predicting the response of populations to varying light fields. (Contact: R. Forbes.)

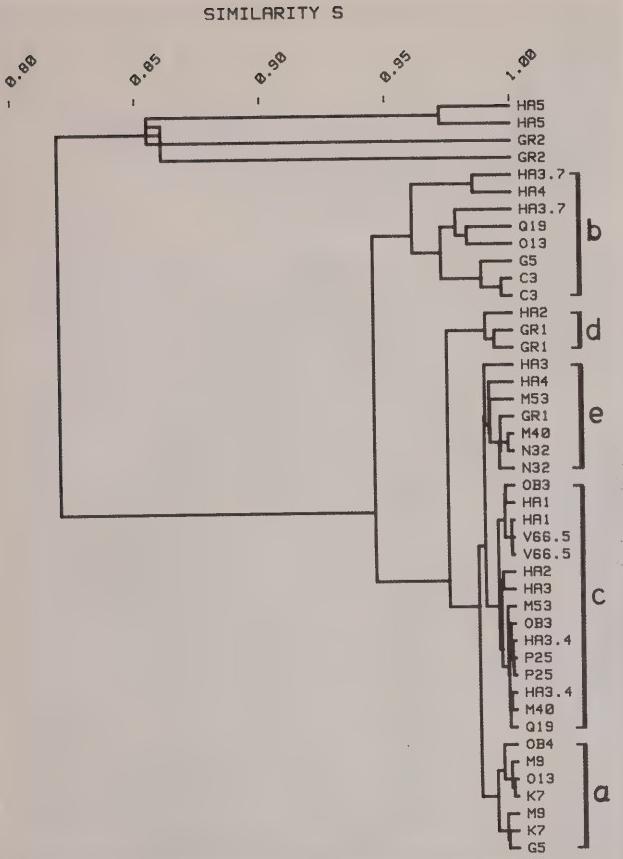
Progress was made on several smaller projects such as the development of phytoplankton cultures using chronoamperometry. This method will give an independent estimate of phytoplankton growth rates in the laboratory. A

preliminary experiment to test the feasibility of measuring the resuspension of sediments by bottom boundary-layer currents was successfully carried out. This experiment involved the simultaneous measurement of turbidity, photosynthetically-active irradiance and current velocity from a mooring at a fixed height above the bottom. The turbidostat system for use in laboratory phytoplankton growth experiments was completed and successfully underwent final testing. A paper describing the system is in preparation. (Contact: S. Hill, K. Denman.)

A five-year field program studying fine-scale (less than one kilometre) zooplankton pattern associated with the Fraser River plume in Georgia Strait was completed with a one-week cruise in May. The dominant zooplankton species (*Neocalanus plumchrus*)

Map shows location of zooplankton community samples taken during cruises in August 1981 and June 1982. The mine tailings discharge is at Kitsault near station M9.





The graph groups samples with similar species composition. The clusters of samples (based on their community structure) correspond closely with spatial segments of the inlet; for example, clusters "a" and "b" include the samples at the head of Alice Arm and closest to the tailings outfall.

occurs in highest abundance around the outer margin of the brackish surface plume. The intensity of this aggregation varies both spatially and with tidal phase and appears to be associated with convergent circulation at the plume boundary.

Data collection for the ship-of-opportunity plankton sampling program was transferred to the Fisheries patrol vessel *Tanu*, which allowed both better spatial coverage and more reliable cruise scheduling. Existing underway sampling gear was installed on the *Tanu* with the addition of a winch for sub-surface sampling. Electronics hardware will be upgraded for the 1984 field season to allow sizing of the zooplankton. A workshop is planned for early 1984 to discuss the sampling program and its accumulated data base.

The analysis of small-scale zooplankton community pattern in the Alice Arm/Observatory Inlet system was completed and results were reported to the DFO's Amax Advisory Panel and submitted to a professional journal. Within each of two sampling periods, the overall range of compositional variability was small. However, statistical techniques such as cluster analysis showed that the highest similarity was between neighbouring samples and that differences in community composition were detectable between different regions of the inlet. Laboratory

studies of mortality, feeding, respiration and swimming behavior were continued in support of the field distribution studies. In general, the physiological impacts of suspended mine tailings (released at mid-depth near the head of Alice Arm) were also small but were consistent with the observed community pattern—species which were usually abundant at the head of Alice Arm were especially tolerant of high tailings exposure, while those with lower tolerance tended to have their highest abundance elsewhere in the inlet system. (*Contact: D. Mackas.*)



Careful washing of samples collected in Alice Arm to assess the impact of mine tailings on the benthic community.

Benthos

The single most exciting event this year was the discovery of an active hydrothermal vent on the Juan de Fuca Ridge by a multi-agency expedition headed by Dr. V. Tunnicliffe, a former post-doctoral fellow of IOS, now on the faculty of the University of Victoria. IOS involvement included microbiological studies in these extraordinary environments. The bacteria obviously play a key role in these communities, in which the basic energy supply for support of life appears to be derived indirectly from the mineral-laden hot water emanating from the vents mediated via the bacteria rather than from sunlight energy through the normal process of photosynthesis. The large and colourful vent worms that characterize the faunas of these vents have no intestines, but instead harbour internal colonies of bacteria that have not so far been cultured outside their hosts. A great many

important biological studies need to be done on this site using *Pisces IV* to locate the site and deploy experiments.

Work on the microflora is related to studies of the anoxic/oxic interface of Saanich Inlet beside the Institute. Production by chemosynthetic bacteria at this interface is being assessed in terms of its significance to the production of plankton at the expense of the benthos in the inlet, which appears to rival the Black Sea as a natural laboratory for such studies. (Contact: S.K. Juniper.)

Analysis of the data from the continental shelf survey described in 1982 has been delayed but specimens have been distributed to experts for verification of identifications. The bulk of the routine material has been deposited with the National Museum of Natural Sciences in Ottawa. Extension of hydrocarbon exploration and possible exploitation will require much better knowledge of the fauna of the continental shelf in the foreseeable future. (Contact: R.O. Brinkhurst.)

The initial study of the benthos in Alice and Hastings Arms in connection with the deposition of mine tailings from the Amax mine at Kitsault was completed. Clear signs of impact of the tailings on the benthos along the deepest trench could be detected, and the already depressed fauna nearer the head end of the inlet (presumably affected by earlier industrial operations) was further reduced. A second set of samples was obtained in a joint Fisheries Management/IOS funded operation with cooperation from the Environmental Protection Service. These samples were obtained after deposition of tailings was halted, and so may reflect any toxic rather than physical burial effects on the fauna, or may show recolonization if any has occurred in the months since mine closure. The samples will be analyzed in early 1984. (Contact: R.O. Brinkhurst.)

In other activities, the distribution of squat lobsters (*Munida*) in Saanich Inlet continues to be monitored along with the oxygen profile using the oxygen probe and the CTD instrument purchased for this purpose. Continued support has been provided for the production of check lists, bibliographies and faunal guides to the benthos and planktonic forms such as mysids and euphausiids. Work on aquatic oligochaetes included identification of verifications and educational services for the consulting community. Evolutionary concepts continued to provide focus for a number of efforts, including the use of computerized objective methods for taxonomic discrimination. Several new species and genera were described and a number of taxa were revised, including a revision of the fauna of Lake Baikal, a source of endemic species. All of the experimental toxicological work of recent years has now been published, and the results have been used to debate the efficacy of environmental management based largely on this laboratory approach rather than on such work coupled with good field ecology.

The grievous loss of Dr. H.R. Baker, who died suddenly while on a field excursion early in the year, was deeply felt by the laboratory in which he had worked so successfully. Considerable efforts have been made to complete his unfinished studies and to distribute his material to appropriate institutions.



Ocean Information



Ocean Information activities support the management, protection and exploitation of marine resources. Primary responsibilities include the collection and dissemination of oceanographic research data, the conduct of marine climatological analyses, the evaluation of environmental reviews, and the provision of information and advice through various committees to regulatory agencies. The Division also oversees the regional ocean dumping research program, provides information to OSS clients, media and the general public, and provides policy and planning support for regional operations.

Oceanographic Data and Climatological Services

Significant progress was achieved during 1983 towards compiling and appraising both Arctic and west coast oceanographic data sets. Four additional Arctic data set catalogues were published. These included physical oceanography for the Northwest Passage and Queen Elizabeth Islands, physical oceanography for Baffin Bay and Ellesmere Island and chemical oceanography for the Northwest Passage. A total of six volumes have been published to date; others covering Beaufort Sea fish, whales and zoobenthos and Canada Basin physical and chemical oceanography will be published in 1984.

The west coast data set catalogue for chemical oceanography of Queen Charlotte Sound, Hecate Strait and Dixon Entrance is progressing well and will be published in 1984 in conjunction with its physical oceanography counterpart. A preliminary compilation of all west coast physical and chemical data sets, without appraisal, for Georgia and Juan de Fuca Straits and for offshore waters will also be published in 1984. Also scheduled for 1984 publication are a review of west coast atlases, marine environmental assessments and data reports focussing on currents, winds, herring, shellfish and marine mammals.

Emphasis continued to be placed on the appraisal of the quality of data sets. This has contributed to the establishment of data archiving priorities in conjunction with the Marine Environmental Data Service (MEDS) and resulted in the highest quality Beaufort Sea physical and chemical marine data being archived in the GF-3 format. Some success has been achieved in devising suitable data set rating criteria for marine biology.

Data set catalogues have been distributed to approximately 300 private and public sector users. An interactive computer data base was instituted to permit quick sort and retrieval of data sets by time, space, quality and discipline. Several other reviews and analyses were completed or near completion in 1983. These include *A Comparison*

of Natural and Petroleum Resource Development Related Fluxes of Metals, Hydrocarbons and Nitrogen, Phosphorus and Silicon to the Beaufort Sea; Weather, Ice and Sea Conditions Relative to Arctic Marine Transportation (jointly with AES) and A Historical Review of Marine Dredging. (Contact: A.B. Cornford, B.D. Smiley.)

During 1983 the B.C. Shorestation Oceanographic Program (lighthouse monitoring program) supplied surface seawater temperature and salinity data from 18 locations. At "open ocean" sites, such as Amphitrite Point and Langara Island, the anomalies in sea surface temperature increased abruptly through December 1982 and January 1983, reached a maximum between March and May 1983, and in general decreased thereafter. Maximum anomalies were between two and three times the standard deviations from the long-term mean. This surface warming appears to be one mid-latitude manifestation of the 1982-83 major El Nino event. (*Contact: L.F. Giovando.*)



Video graphics terminal used for accessing Ocean Information data bases. Work station includes dot matrix printer and a graphics plotter.

Environmental Services

IOS continued to give substantial support to the Arctic Waters Advisory Committee (AWAC) and the Arctic Regional Ocean Dumping Advisory Committee (RODAC) in reviewing offshore oil and gas activities, oil spill contingency plans, regulatory requirements and dredging/dumping proposals. Formal reviews were undertaken for west coast RODAC and considerable advice was given regarding the dredging of False Creek in Vancouver. (*Contact: A.B. Cornford.*)

Scientists at IOS undertook a very detailed technical review of both the Beaufort Sea Environmental Impact Statement (EIS) and its Supplement, and Ocean Information Division made substantial contributions to the EARP public hearings at Inuvik and to the DFO position paper. Reviews of several major initiatives—a CMO

proposal to drill for oil in Lancaster Sound, proposed port developments at King Point and Stokes Point, and the Beaufort Sea Environmental Monitoring Project (BEMP)—were completed on behalf of the Department of Indian Affairs and Northern Development (DIAND). (*Contact: B.D. Smiley.*)

Detailed reviews of Initial Environmental Evaluations (IEEs) prepared by Petro-Canada and Chevron Canada relating to proposed offshore drilling in Canadian west coast waters contributed to a workshop sponsored by the Canadian Oil and Gas Lands Administration (COGLA) and the B.C. Ministry of Energy, Mines and Petroleum Resources. A departmental technical submission and position statement will be prepared for a joint federal-provincial Data Forum established to assist a formal public review process scheduled for 1984. (*Contact: L.F. Giovando.*)

Ocean Dumping

IOS administers the Ocean Dumping Control Act research fund for both western Arctic and Pacific marine waters. Research results are reviewed and published in the proceedings of an annual workshop. The Institute also serves in an advisory capacity regarding all marine dredging and dumping permits issued by DOE's Environmental Protection Service. Emphasis in 1983 centred around disposal options for False Creek and Alberni Inlet dredge spoils, while 1984 will focus upon a protocol for reporting accurate and precise data. (*Contact: L.F. Giovando.*)

Information and Media Relations

The third in a new series of IOS Annual Reviews was completed along with contributions to various publications including departmental and inter-departmental annual reports. Updates of Institute research activity and other noteworthy events were combined in a monthly report for the OSS Assistant Deputy Minister. Articles covering various facets of IOS works were placed in various trade and special interest publications.

IOS set up several temporary displays in B.C. in 1983 including "From Leadline to Laser", marking the centennial of the Canadian Hydrographic Service and provided extensive media liaison for events such as the historic *Pisces IV* dives to offshore Juan de Fuca Ridge hot vents.

Preparations have begun for participants in the Canada Pavilion at the 1984 Pacific National Exhibition and discussions have taken place regarding IOS involvement at Expo '86. (*Contact: K. Glover.*)

Policy/Program Analysis

A major review of departmental planning included a Review of Estimates exercise, a new Operational Planning Framework and reworked objectives, a Multiyear Operational Plan (MYOP), a Summary Operational Plan, Work Plans and a Program Review and Evaluation (PRE). A major audit of the physical oceanography program was undertaken by the Audit and Evaluation Branch, Ottawa and progress reports covering IOS activities were submitted to the Office of Energy Research and Development (OERD).

Ships



Currently under construction at Bel-Aire Shipyard Ltd. in North Vancouver, a new oceanographic and hydrographic ship for IOS.



Pisces IV submersible

Ships



The Pacific Region Ship Division provided ship, submersible, launch and depot support for the 1983 scientific and hydrographic programs of the Institute of Ocean Sciences, the Pacific Geoscience Centre (PGC), universities and other federal agencies.

Of extreme importance in 1983 was the contract award for the construction of a 69-metre vessel to replace the *CSS Wm. J. Stewart*. This new vessel, expected to be in service in 1985, will not only add another dimension to the IOS fleet but will go a long way towards relieving the excess demand for existing vessels.

CSS PARIZEAU (64.3 m overall; 1929 tonnes)

Master: A.G. Chamberlain *Chief Engineer:* P. Pereira

The mid-life refit was completed successfully. The new arrangements for accommodation and the re-engining of the vessel have been major contributors to increased efficiency.

CSS Parizeau resumed service as a primary Search and Rescue (SAR) vessel for the herring roe fishing fleet. For the remainder of the year the ship was employed in support of scientific programs involving Ocean Physics, Tidal and Current Surveys, Ocean Chemistry, EPS, Department of National Defence, PGC and the University of British Columbia (UBC).

CSS VECTOR (39.6 m overall; 505 tonnes)

Master: R.W. MacKenzie *Chief Engineer:* R. Pearson

CSS Vector provided support for the scientific programs of Ocean Physics, Ocean Chemistry, Ocean Ecology, EPS and UBC.

CSS RICHARDSON (19.8 m overall; 78 tonnes)

Master: (Acting) J. Campbell/A.S. Coombes

CSS Richardson was used by the Hydrographic Division in field surveys in the Quatsino Sound and Ridley Island areas. *Richardson* also spent several weeks on SAR duties during the herring roe season.

M.V. PANDORA II on charter (58.2 m overall; 1220 tonnes)

Master: S. Gulati *Chief Engineer:* R. Rogers

The *Pandora II* was employed in support of scientific programs involving Ocean Ecology, EPS, Pacific Biology Station, Simon Fraser University, UBC and University of Victoria. The majority of these programs were in conjunction with the submersible *Pisces IV*.

PISCES IV: (6.1 m overall; 12 tonnes)

Chief Pilot: F. Chambers

At the beginning of 1983, the submersible *Pisces IV* was transported by a Canadian Armed Forces Hercules aircraft to the Naval Ship Research and Development Centre at Annapolis, Maryland. The *Pisces IV* was fitted to a special cradle and placed in a pressure chamber where a test pressure of 3200 p.s.i. was applied. This is the simulated equivalent of 2000 metres, the depth to which the *Pisces IV* is now certified to dive. On her return to IOS, in conjunction with the mothership, M.V. *Pandora II*, *Pisces IV* was employed in support of Ocean Ecology, University of Victoria, Simon Fraser University, Dept. of National Defence, Pacific Biological Station and EPS.

Barge PENDER

The *Pender* was used as mothership by the *Pisces IV* early in the year and later was used extensively by the Hydrographic Division in support of field surveys in the Gunboat Channel, Spiller Channel and Milbanke Sound areas.

Institute Workshops

The Depot staff were responsible for the repair and maintenance of the Institute's fleet of over 30 launches and small boats as well as providing support for the *Parizeau*, *Vector* and *Richardson*. Mechanics were supplied to the *Pender* and *Polar Circle* during their hydrographic service and depot personnel were also involved in the development and testing of scientific equipment such as the Active Drifter and the Stern Tow.

Deck Machinery

Deck Machinery staff were responsible for the ongoing maintenance of winches and support gear for the various scientific cruises. Service was also provided in the fitting out of the charter vessel M.V. *Polar Circle* for its hydrographic duties in the Arctic.

Management Services

Management Services



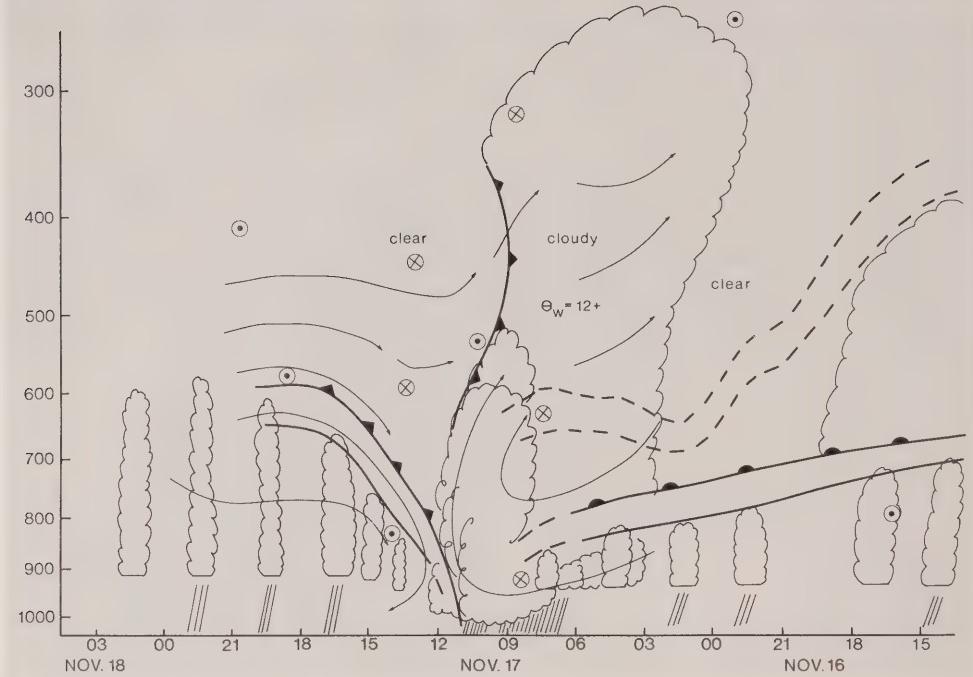
In 1983 continued emphasis was placed on increasing productivity, reducing the paper burden and using current technology in performing administrative functions.

User requirements were drawn up for a system called AIMS (Automated Integrated Management System) which is designed to use a regional computer base and intelligent desk top terminals to perform some of the basic tasks in a logical sequential work-processing flow. These tasks include purchasing, expenditure and commitment control, accounts payable and receivable, fixed asset and equipment distribution, person-year control. A proposal was made to departmental headquarters to fund two pilot systems for AIMS, one at IOS and one in Fisheries Management, Pacific Region. A significant feature of the proposal is that the design and commissioning of the system will involve the Central Accounting Branch of the Department of Supply and Services.

The energy conservation program was active again in 1983. Double glazing of the main building was completed and improvements were made to the heating and ventilation system. In terms of cost, the largest job undertaken for energy conservation purposes was the insulation of the hangar building. Electric heating and double-glazed windows were also installed. Two more vehicles were converted to propane use.

The library received two large gift collections which are gradually being incorporated. These will substantially enhance the collections in the areas of meteorology and in oceanographic journals. The Institute's librarian was elected chairman of the Council of Fisheries and Oceans' Librarians for the upcoming term.

DEPARTMENT OF THE ENVIRONMENT



Vertical cross-section through weather front over the ocean. The warm and cold fronts are indicated by heavy lines. The arrows indicate air motions. Crosses and dots indicate air motions away from and towards the reader. Clouds and rain are shown schematically.

Atmospheric Environment Service



Atmosphere-Ocean Interaction

Studies have continued of storms over the northeast Pacific Ocean. Warm and cold frontal systems are usually associated with precipitation and major changes in weather conditions. By using weather radar and balloon-borne instrument packages, launched from a ship, the structure of such a system has been extensively investigated. Bands of cloud elements were found to move with the cold front, providing most of the heavy precipitation. The rain associated with the warm front was more widespread, and continuous but of lighter intensity. A schematic cross section of the storm shows the gently sloping warm front and much steeper cold front. The cloud area aloft is fed mainly by moist, warm air moving up near the cold front. As the system moves easterly, warm, moist air from the south moves northward in advance of the cold front and then rises. As it rises it mixes with faster moving air aloft and moves eastward. For this case, this stronger winds aloft have created an upper front which is separate from the surface feature. After frontal passage, the air is cooler aloft and warmed by the ocean surface, creating convective showers. Further understanding of these types of storm systems will lead to an enhanced ability to model and predict weather systems arriving at the Pacific coast.

Atmosphere-ocean exchanges of heat play a major role in determining the earth's climate. An historical data set for the North Pacific Ocean, covering over 25 years, has been examined to determine the spatial and temporal variations in the monthly averaged heat flux. There is, as expected, a large annual cycle but this cycle is quite different from year to year. The inter-annual variability also differed for various areas of the ocean basin. This variability is related to the variations in the oceanic heat transport. Studies have begun to investigate this relationship. Two different TransPacific sections of deep hydrographic stations are being investigated and a measure of the variability determined. (*Contact: G.A. McBean.*)

Precipitation Chemistry on the Pacific Coast

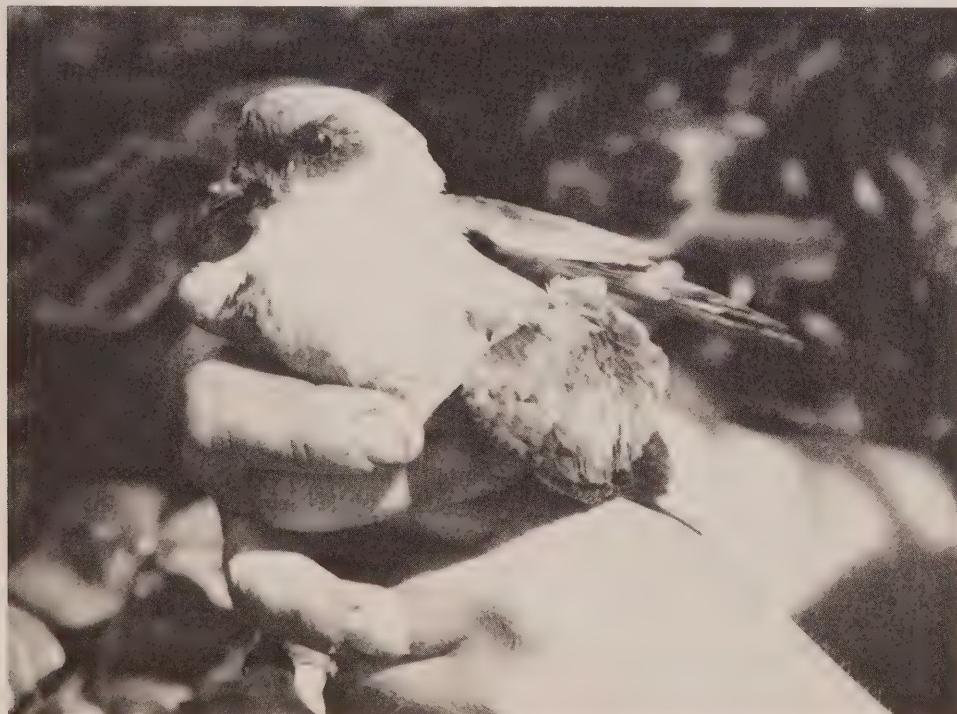
Collection and analysis of rain and snow samples at IOS, on ships and at Mount Washington continued. Analysis of the snow core samples, collected jointly with Pacific Region, AES, Vancouver, has allowed the mapping of the precipitation chemistry in the southwestern coastal region. Since the pH of "clean" precipitation in

equilibrium with atmospheric CO₂ is 5.6, only the snow in areas near Georgia Strait/Vancouver is significantly depressed due to contributions from sulphuric and nitric acids. On Vancouver Island and the interior region the sulphate values were generally below the detectability levels of the analytical procedures used. These results indicate that the long-term measurements taken at Vancouver are probably representative for the Georgia Strait/Vancouver area but not for more distant locations. (*Contact: G.A. McBean.*)

Canadian Wildlife Service



Field studies in the Queen Charlotte Islands continued in 1983 on two seabird species, the Ancient Murrelet and the Cassin's Auklet, both of which dive for their food. In addition, a research program was initiated on Fork-tailed and Leach's Storm-Petrels, which do not dive, but dip in surface waters to forage on amphipods, jelly fishes and fishes. Both species nest on small offshore, wooded islands in the Queen Charlotte Islands. Their feeding habits differ in that the Leach's Storm-Petrel feeds predominantly in warm waters beyond the continental shelf, while the Fork-tailed Storm-Petrel forages mostly over colder shelf waters in summer and fall. The Fork-tailed Storm-Petrel nests from April until the end of September, and the Leach's Storm-Petrel, the latest nesting seabird on the B.C. coast, from June until the beginning of November. Both storm-petrel species lay a single egg each at the end of a nesting burrow in the soil. The young storm-petrels spend two months in their burrows before they are able to fly; a much longer nestling period than that for any other seabird in British Columbia.



Fork-tailed Storm Petrel

The distribution of the two storm-petrels was also investigated at sea during IOS cruises in Hecate Strait, Queen Charlotte Sound and on the west coast of the Queen Charlotte Islands. Those cruises not only provided information on storm-petrels but also on the distribution and populations of other pelagic seabirds. The most numerous species observed on the sea cruises were Sooty Shearwaters, which are pursuit divers and which nest in the southern Pacific and visit B.C. waters during our summer. Millions of shearwaters pass through Hecate Strait and Queen Charlotte Sound in May and it is not uncommon to see feeding flocks numbering 50,000 to 100,000 birds.

The information on pelagic seabird distribution and populations will be valuable in obtaining a first glimpse of the importance of the seabird resource on the continental shelf. Of all resources, seabirds are most at risk from oil spills. Oil companies have now made applications to conduct exploratory drilling for oil and gas. The present moratorium for offshore drilling may be lifted for Shelf waters between southern Alaska and northern Vancouver Island. It is precisely there, and not in the Straits of Georgia and Juan de Fuca, that there are unique and almost pristine populations of seabirds which Canadians are just beginning to enjoy. It is therefore essential that a thorough investigation of this resource is conducted before the moratorium is lifted.
(Contact: K. Vermeer.)

**DEPARTMENT OF
ENERGY, MINES
AND RESOURCES**

Pacific Geoscience Centre



Geological Survey of Canada and Earth Physics Branch



Director's Foreword

Many new developments occurred at the Pacific Geoscience Centre (PGC) during 1983 in a broad range of disciplines including the geology of the continental margin and adjacent offshore, marine geophysics and geophysical studies of the Cordillera. Specifically these studies include fjord, estuarine and deltaic sedimentation and structure, coastal sedimentary processes, micropalaeontology and related geological field mapping, palaeomagnetism, geomagnetic studies, gravity, geodynamics, seismicity, geothermal energy and plate tectonic interactions.

A notable development was the much expanded Juan de Fuca Ridge study which included extensive SEABEAM and SEAMARC II high resolution bathymetry and acoustic images. This research was undertaken in cooperation with NOAA, the University of Hawaii and Canadian Hydrographic Service. The results of these investigations along with the multiparameter resource charting activities in the area, provide an essential background for detailed ship and submersible studies of ridge hydrothermal processes and related sulphide mineralization.

Renewed interest in offshore petroleum exploration has provided an impetus towards a better understanding of the character and structure of the offshore sedimentary basins. As a result, new studies have been initiated in the Queen Charlotte Sound and Hecate Strait areas (Queen Charlotte Basin). These include the nature of the seafloor sediments and particularly their stability in the event of earthquake activity, structure of the basinal sediments and their geological history. Equivalent rock units of Jurassic, Cretaceous and Tertiary age are under intensive study on the adjacent Queen Charlotte Islands. Petroleum exploration has also spurred PGC earthquake monitoring in the Beaufort Sea and on the Grand Banks of Newfoundland.

A very successful meeting of the GAC/CGU/MAC was held at the University of Victoria in May. Much of the organization was carried out by geologists of PGC and the B.C. Department of Energy, Mines and Petroleum Resources to whom hearty congratulations are extended.

Two new developments will have significant future impact on PGC activities. An agreement between EMR and NSERC on behalf of a number of universities paved the way for a continuing major program of deep crustal studies in Canada (LITHOPROBE). The investigations will employ seismic techniques as well as a wide range of other geological and geophysical disciplines. The first profile will be across Vancouver Island in 1984. The second important development was the steps taken

for Canada to become a member of the next phase of the international Deep Sea Drilling Project (DSDP). This project will undoubtedly involve many PGC scientists and should result in eventual drilling of deep sea holes in the Juan de Fuca Ridge area.

The Pacific Geoscience Centre had an extremely productive year, and it is to the credit of an outstanding staff that our organization is gaining recognition worldwide. (R.D. Hyndman.)

○ ○ ○ ○ Sedimentology ○ ○ ○ ○ ○ ○ ○ ○

Estuarine and Marine Delta Sedimentation

As in previous years demand remained high for geological data from the Fraser River Delta to help formulate environmental/engineering guidelines. Results of geological research have been applied to investigations by outside agencies relating to the proposed Iona Island sewage pipeline, Westshore Terminals coal port expansion and the B.C. Hydro proposal for a Vancouver Island gas pipeline. In addition, this year a demand arose for sedimentological information regarding potential new anchoring sites for large freighters in the Prince Rupert/Skeena Delta/Chatham Sound area.

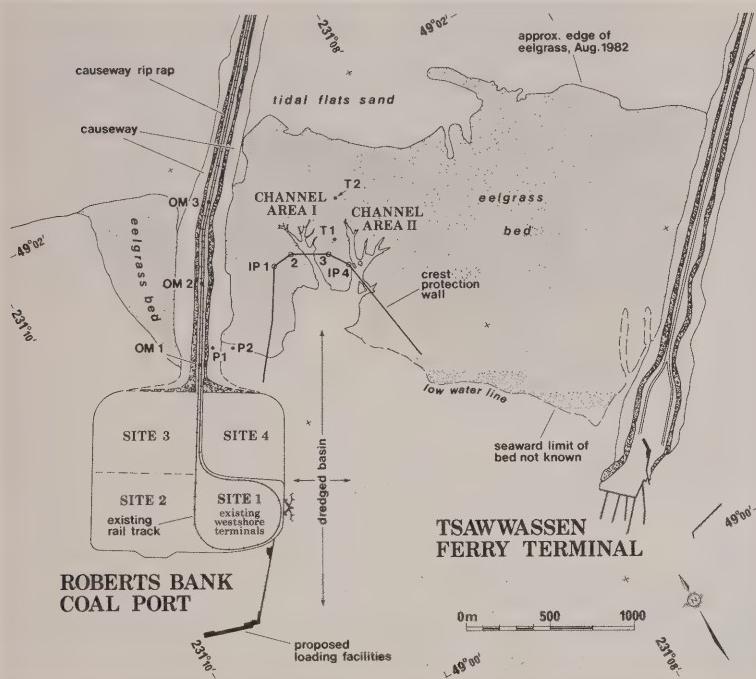
The highlight of the summer's field activities was the surveying, mapping and assessment of mechanisms influencing tidal creek erosion adjacent to the Roberts Bank Coal Port on the Fraser River Delta. Work was performed in association with students from the Engineering (Geological) Department of U.B.C. and Engineering Technology Department at the British Columbia Institute of Technology. (*Contract: J. Luternauer.*)

Continental Shelf Sedimentation

Research proceeded on the mapping of the heavy mineral, lime, gravel and sand deposits in Queen Charlotte Sound, employing side-scan sonar and a vibracorer. This study will be coupled with a forthcoming survey of local geological hazards to development.

Preliminary lithologic descriptions were completed, enclosed shell matter was submitted for radiocarbon dating, and a preliminary assessment of the environments of deposition was undertaken with the assistance of Marine Geology and Geophysics

Section of cores (the longest of which is 8 m) collected during the *Hudson 81* cruise in Queen Charlotte Sound. These cores offer the longest continuous record of late Quaternary sedimentation available for the continental shelf of western Canada.
 (Contact: J. Luternauer.)



Dendritic creek erosion at the head of dredged ship basin adjacent to Roberts Bank Coalport, Fraser River Delta. The creeks have eroded into an ecologically valuable eelgrass bed in response to the focusing of ebb tidal flow into the ship basin. The crest protection wall was erected to inhibit further erosion by slowing seaward water flow and trapping sediment. OM represent survey markers; T represents navigation towers.

Coastal and Sedimentological Studies

Research focussed on the effects of sediment transport on grain size distributions. A simple model was developed to demonstrate that sediment in transport must become progressively finer and more negatively skewed whereas sediment remaining (a lag) must become coarser and more positively skewed than its source. Successive deposits derived from sediment in transport can become coarser or finer in the direction of transport with the skewness becoming more positive or more negative respectively. By comparing the relative changes in grain size distributions from deposits of a variety of environments (i.e. beach, nearshore or shelf) a pattern of sediment transport can be predicted.

In this way the sediments have, in fact, integrated over time all the processes responsible for their erosion, transport and deposition. Given the high cost for

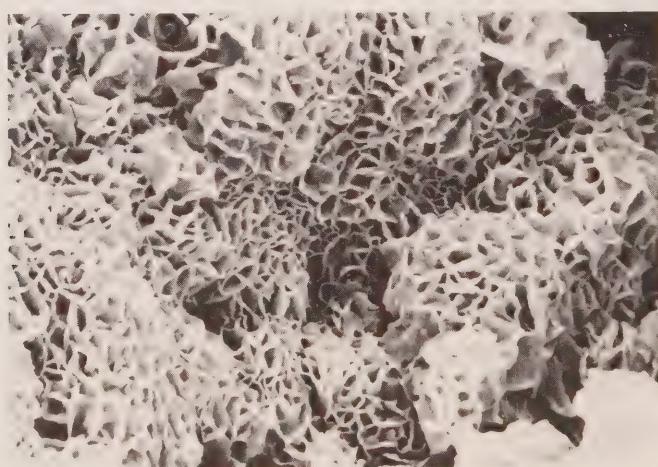
certain process studies, this kind of analysis is both relatively inexpensive and rapid. The sediment transport model has proven effective in predicting the pattern of oil movement in the coastal zone and may be a useful method in determining the fate of hazardous waste, heavy mineral concentrations and the location of placer deposits. (Contact: P. McLaren.)

Coastal mapping for the purposes of oil spill contingency planning was continued on the Queen Charlotte Islands. The program was designed to collect baseline data on the sedimentology and geomorphology of the shoreline. In a joint program with Petro-Canada, all "mappable" variables are treated independently and stored in a mini-computer system which enables future manipulation to obtain the most meaningful map units. Each variable can be correlated with any or all of the others to determine their spatial relationships and their possible interdependence. In this way, maps can be produced easily to serve a variety of purposes; for example, user-specific data maps for oil spill contingency planning or shoreline development as well as fundamental coastal research. (Contact: P. McLaren.)

Marine Sedimentology

A one year assignment at the Centre de Recherches de Sédimentologie Marine, Université de Perpignan, France, was completed in August, 1983. During this period a study of the nature, genesis and distribution of glauconie on the Vancouver Island continental shelf was undertaken with Pierre Giresse using microprobe, atomic absorption spectrophotometry, x-ray diffractometry and light microscopy. Glauconie is a family of green authigenic iron- and potassium-rich clay minerals. After returning to PGC, further studies of glauconie were completed with GSC support using scanning electron microscopy. (Contact: B.D. Bornhold.)

Boxwork form of authigenic glauconie from the Vancouver Island continental shelf.





*Pillow lavas and thin covering of sediment.
Dellwood Knolls.*

A detailed morphological synthesis of the 1975 submarine landslide in Kitimat Arm was completed in conjunction with the Coastal Studies Institute at Louisiana State University. The analysis includes a partial side-scan sonar mosaic of the area, a map of surface topographic features, the 1952 and 1981 bathymetries, a map of bathymetric change due to landslide events, computer drawn block diagrams of the pre- and post-slide bathymetries, and a block diagram of the principal morphological elements of the slide.

In September a successful cruise of CFAV *Endeavour* was undertaken in cooperation with Henri Maillot and Bertrand Blaise of the University of Lille (France). During the cruise 26 sediment cores, deep sea photographs and water temperature measurements at 10 sites, and several hundred kilometres of continuous high resolution seismic profiles were obtained in the vicinity of the Dellwood Knolls. Mineralogical and chemical studies are being carried out by scientists at Lille. (*Contact: B. Bornhold.*)

Sedimentology Laboratory/Data Section

The sedimentology laboratory provides technical and analytical support for the marine geology subdivision. The primary activities are aiding in the collection of soft sediment samples, describing them and carrying out grain size analyses. The samples, taken by bottom grabs, cores and dredges, are collected from coastal, estuarine, deltaic, continental shelf and continental slope environments. Grain size is determined using sieves for gravels, a settling tube for sands and a sedigraph for the mud fractions. About 1000 grain size analyses were processed throughout the year.

The data section of the sedimentology laboratory maintains an inventory of samples collected or donated. (The current total is in excess of 7500.) It is also

responsible for the archiving of those samples as well as handling requests for data and subsamples. Six groups outside of the Pacific Geoscience Centre contributed samples in the past year and twenty requested data and/or sub-samples. (*Contact: T. Forbes.*)



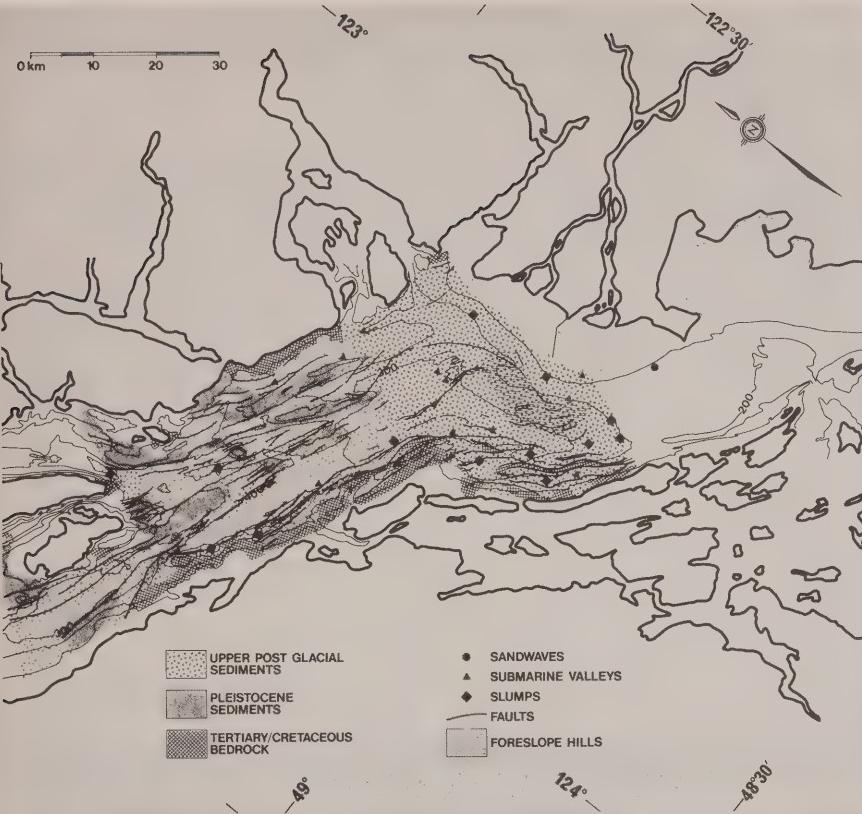
Marine Geology and Geophysics of Georgia Strait

Geological, geophysical and geotechnical information on the Strait of Georgia is currently in high demand apropos of the proposed natural gas pipeline crossings, spoils dumping schemes, site specific surveys and various academic projects. New data to meet these needs were collected during 1982 and 1983 in a series of 5 cruises aboard the *CSS Vector* and *CFAV Endeavour*. Investigations include both Canadian and American portions of the Strait. The data base currently under analysis includes over 2000 km of seismic and high resolution sub-bottom profile lines, magnetometer and sidescan tows and over 60 cores (gravity and vibracore samples) from the Quaternary to Recent unconsolidated sediments. The overall purpose of these investigations is to understand better the geological history from the sedimentary and seismic records and to present the data for public use. Of particular interest is the widespread distribution of features suggesting seafloor instability; chiefly faults, slumps and submarine slides. Cooperation with private industry, academic institutions and other government departments has been high. (*Contact: T.S. Hamilton.*)

Bedrock Studies — Continental Margin

A start was made on a study of the basin evolution of the Georgia Depression in terms of its association with Cretaceous and Tertiary plate tectonic processes affecting the continental margin. Its identification as a back-arc or fore-arc basin is unclear; there are arguments to support both origins. Detailed stratigraphic and sedimentological studies in association with paleobathymetric analyses based upon Foraminifera will be applied to regional facies distributions so as to delineate shallow and deep depocentres. Detailed sampling for porosity and vitrinite reflectance, as well as for thermal conductivity determinations was begun. This work will provide information on the basin's subsidence and thermal history. Several industrial multichannel seismic lines were examined for preliminary structural control beneath the basin. The Tertiary section encountered in the three Atlantic Richfield wells on the lower mainland were examined. (*Contact: C.J. Yorath.*)

Renewed interest in hydrocarbon exploration both on and offshore in the Queen Charlotte Islands, and a keen international interest in the Juan de Fuca Ridge system,



Map showing Quaternary geology of Georgia Strait



Polygonal jointing in a Basaltic Volcanic Neck, Skaga Is.

require a better understanding of various volcanic rock units in the Insular Belt and offshore regions adjacent to western Canada. Understanding the origin of the volcanics erupted in a given environment is essential to comprehending the evolving tectonics and deep seated geological processes.

The Tertiary Masset Formation, well represented in the Queen Charlotte Islands and nearby offshore, has abundant basic and sialic lavas with hydrocarbon shows. Petrographic, petrochemical, isotopic and paleomagnetic studies are underway to help elucidate the genesis of the lavas and to discern their subsequent tectonic motions. The volcanic rocks of the Jurassic Yakoun Formation are the subject of similar studies which will help to constrain the models for earlier parts of the geologic column. Preliminary investigations have also been made of the Tertiary Metchosin and Alert Bay volcanics on Vancouver Island, and of the submarine lavas of the modern day triple junction at the northern end of the Juan de Fuca Ridge (Dellwood Knolls and J. Tuzo Wilson Knolls). (*Contact: T.S. Hamilton.*)

Technical Services

Technical Services provides electronic and mechanical engineering support for the Marine Geology and Geophysics group, and the Paleomagnetic Laboratory. The main thrust is in the maintenance and operation of scientific equipment and upgrading of existing equipment.

Two hydrophone arrays with built-in preamplifiers were designed and built for shallow continuous seismic reflection profiling to improve an analogue seismic data acquisition system for the Quaternary geology of Georgia Strait project. A feasibility study and purchase of a multichannel digital seismic system to replace two single channel digital systems was undertaken. The system will be capable of digitizing six channels of data up to 1 kHz and one channel of 3.5 kHz.

The rock magnetic properties laboratory was completed and the paleomagnetic laboratory acquired an IBM personal computer in preparation for the next step in the automation of data processing. (*Contact: I. Frydecky, W. Hill.*)

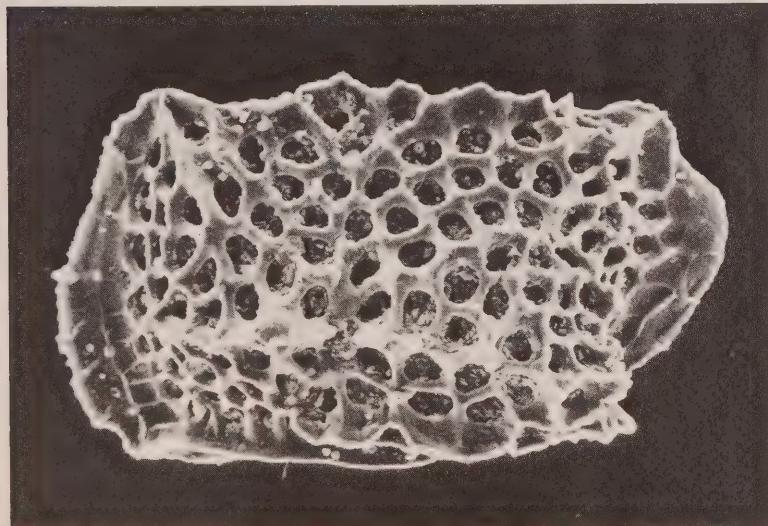
During 1983 technological and operational improvements included the purchase of a high pressure air compressor (150 scfm). In marine seismic studies it allows for refraction profiling in conjunction with the University of British Columbia's large air gun (2000 cu. in.), as well as upgrading our reflection profiling capabilities with the 300 cu. in. air gun in the offshore regions. With new heavier coring equipment (2000 lbs.), cores of unconsolidated sediments can be taken up to 12 metres in length. Use of an Emerson-Maclntyre vibracore from the Atlantic Geoscience Centre enabled core sampling in sandy areas in Queen Charlotte Sound and the Strait of Georgia, which were not previously obtainable. Modifications to our dredging gear include the use of teeth on box dredges for greater sample recovery and net liners to preserve fragile samples. (*Contact: G. Jewsbury.*)

Palaeontology

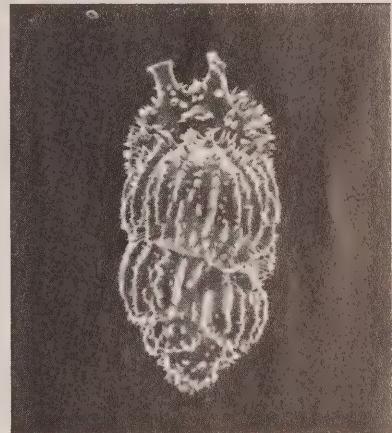


Activities in micropalaeontology and biostratigraphy at PGC cover a broad spectrum of investigations in rocks ranging in age from Jurassic to Quaternary from both subaerial exposures and offshore localities. Studies in the biostratigraphy of the Jurassic and Cretaceous rocks of the Queen Charlotte Islands are continuing. This topic deals with correlating the various rock units principally by the use of foraminifers and mapping their distribution and tectonic history. Observations as to their petroleum source bed potential and hydrocarbon shows have also been made.

Studies in Late Quaternary sedimentation and stratigraphy are being aided by extensive use of ostracod biofacies investigations on the continental shelf, the Georgia Strait and the deep sea. The largely undescribed ostracod populations of the west coast have been found to be excellent environmental indicators and as well suggest sources of the enclosing sediment and explain sedimentary distributional patterns. Excellent, and in some cases, unusual ostracodal and foraminiferal populations have been recovered from cores around the deep sea spreading ridges. The purpose of this study is to investigate the possibility that the occurrence and distribution of some of these forms is at all related to thermal vents. (Contact: B.E.B. Cameron, M. Johns.)



Deep sea ostracod *Encytherura* sp.

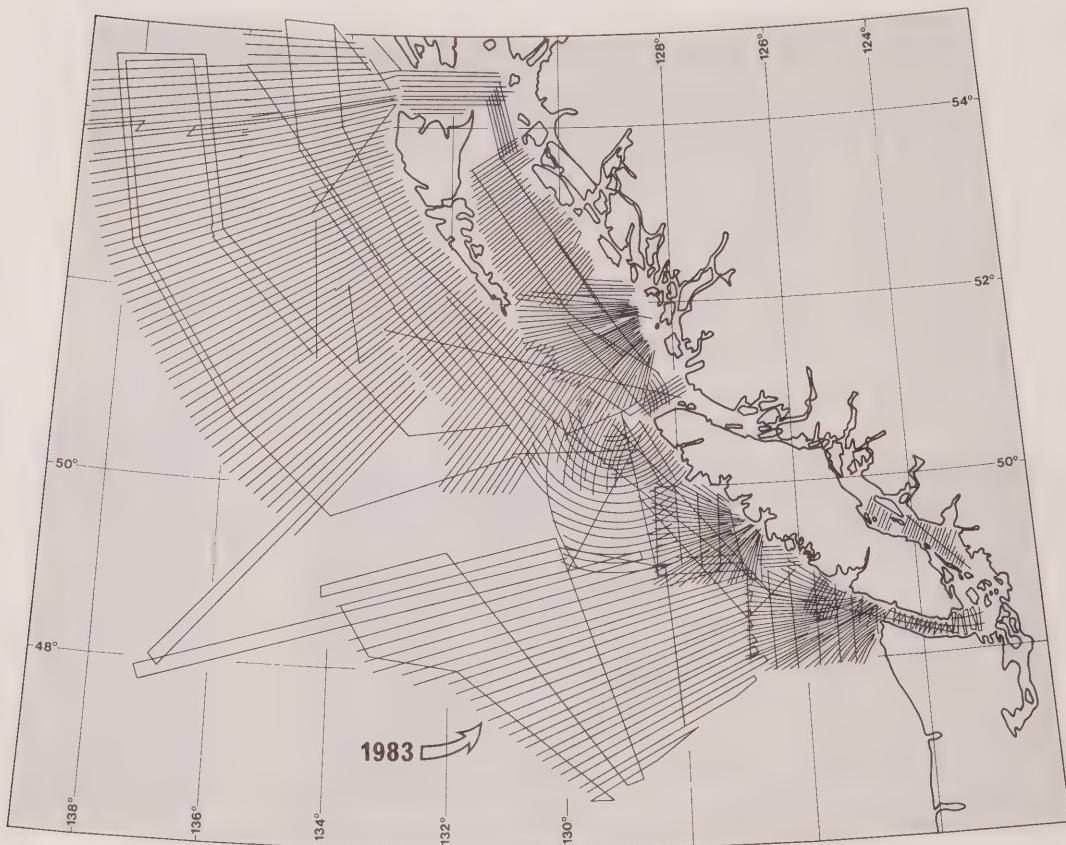


Aberrant foraminifera *Uvigerina dirupta*.
Note doubling of terminal principal aperture.



Multiparameter-Geophysical Surveys

Systematic magnetic, gravity and bathymetric surveys are being conducted over the Canadian Economic Zone to help assess the economic potential of the region and its tectonic framework.



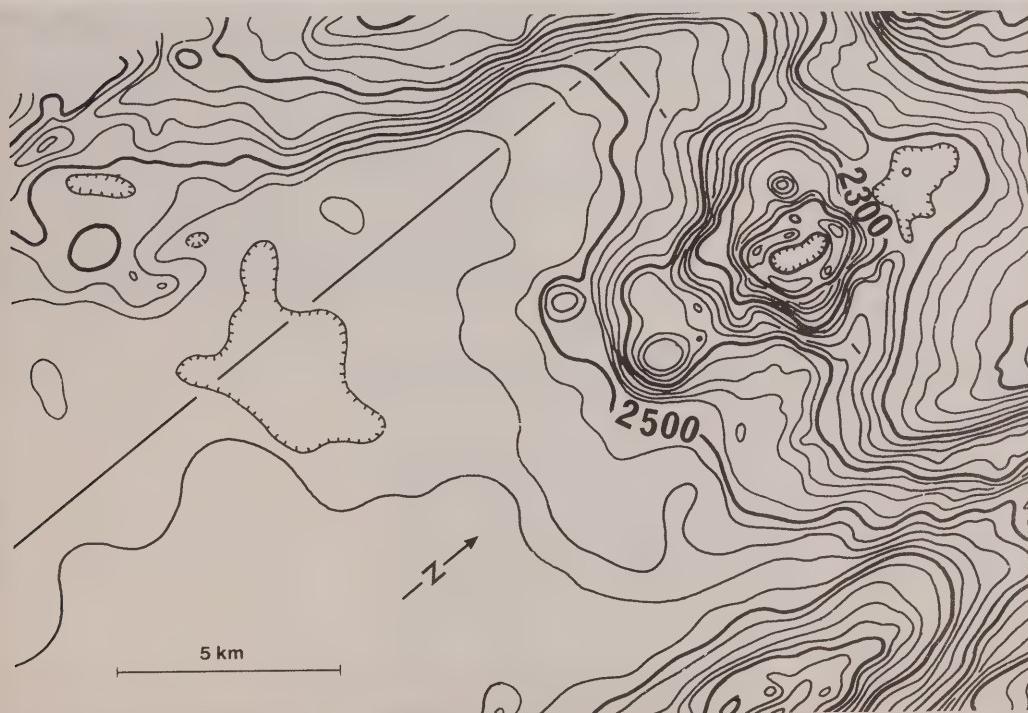
Composite ship's track showing coverage obtained from 1973 to 1983 inclusive

The 1983 marine program consisted of a 5-week, multiparameter survey aboard the CSS *Parizeau* during which time 13,500 kilometres of geophysical data were collected. The region covered was south of last year's survey area between the 47th and 49th parallels. Approximately one more field season is required to complete the coverage of the Canadian Economic Zone. One dynamic gravimeter was carried on this cruise, the SL 1, a prototype linear design meter first introduced in 1980. Refinements to this instrument during the last few years, coupled with reasonably good weather during the survey, brought about extremely accurate gravity

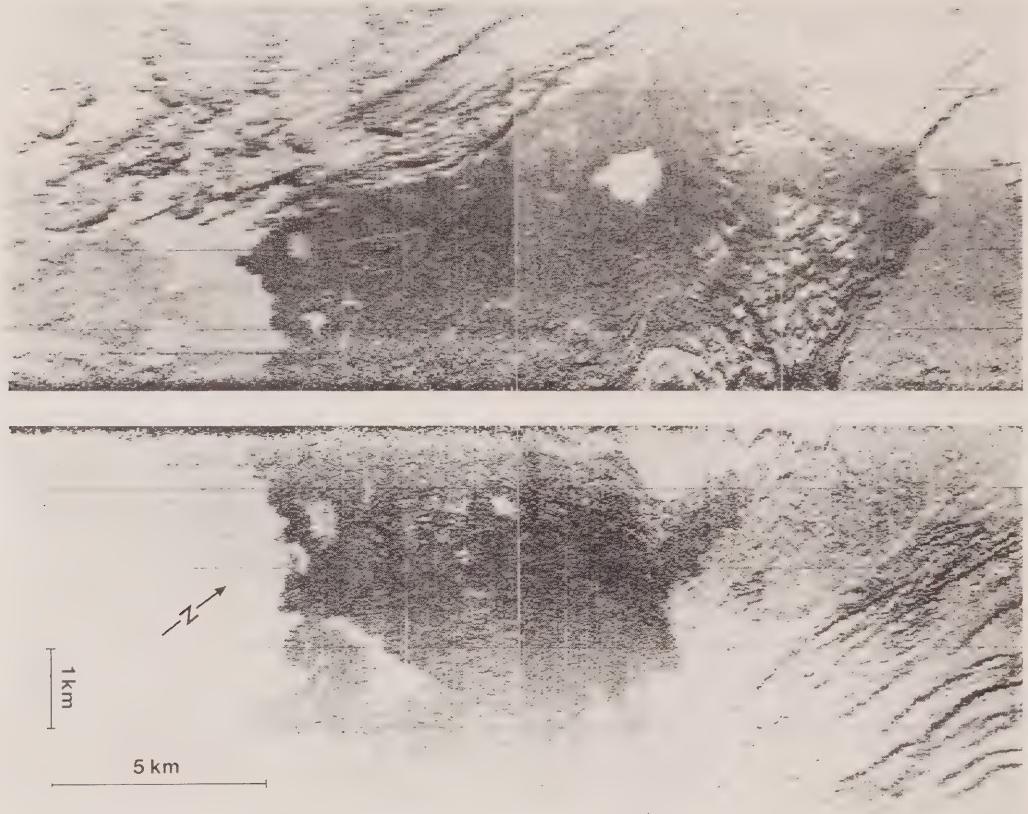
measurements; adjusted trackline intersection values were within ± 0.7 mGals (seven parts in 10,000,000 of the earth's gravity). The two test lines, extending 550 km offshore, place limits on the position of the propagating rift trace in this previously unsurveyed portion of the northeast Pacific. (Contact: R.G. Currie, R.P. Riddihough, D.A. Seemann.)

Juan de Fuca Ridge Mapping

New data was collected from the northern Juan de Fuca Ridge system in order to characterize better the tectonic processes and to allow preparation of detailed bathymetric and geological maps. Detailed bathymetric mapping from the NOAA Ship *Surveyor* was carried out in cooperation with National Ocean Surveys using SEABEAM, a multi-beam swath sounding system that produces 10 metre contours over a region that is 2/3 of the water depth under the ship. Maps at a scale of 1:50,000 showing 10 metre contours, were prepared for release in Open File for the Tuzo Wilson Knolls, Explorer Ridge, the Sovanco Ridge and Fracture Zone and the northern Juan de Fuca Ridge.



SEABEAM bathymetry over the Juan de Fuca Ridge at $48^{\circ} 15'N$, $129^{\circ} 13'W$ (20 m contour interval)



SeaMARC II side scan image of the same area showing recent volcanism and rifting associated with spreading processes

SeaMARC II side scan (backscatter and bathymetric) imagery, seismic reflection and 3.5 kHz acoustic profiling data were also obtained from the R.V. Kana Keoki of the University of Hawaii working under contract to PGC and CHS. Areas covered were Tuzo Wilson and Dellwood Knolls and the northern Juan de Fuca Ridge. These data afford a new, possibly definitive, look at a spreading ridge. (Contact: E.E. Davis, R.P. Riddihough, R.G. Currie.)



Seismological Service



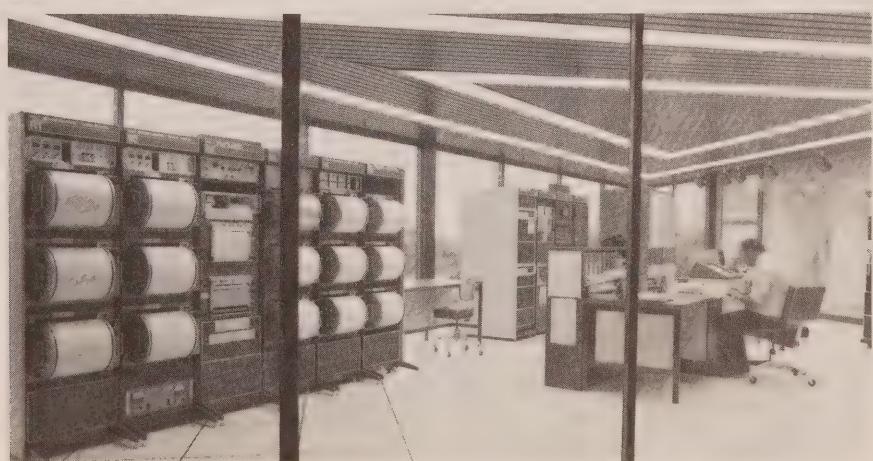
The Seismological Service provides earth scientists, civil engineers, resource development industries and the public with basic earthquake data, and with research information concerning natural and induced earthquakes, ground motion seismic risk, earth structure, and nuclear explosions. This is accomplished through a network of

seismological stations, including standard and regional stations, two telemetered arrays, strong motion accelerographs and special installations.



Solar-powered, mountain-top radio telemetered digital seismograph station

Recording centre for digital telemetered seismograph network



Seismic Networks

The Western Canada Telemetered Network (WCTN), established to provide centralized, on-line monitoring of seismicity in southwestern British Columbia, was expanded in 1983 by two stations. Fourteen stations are now being recorded at the Pacific Geoscience Centre (PGC). (*Contact: D.H. Weichert, G.C. Rogers, M. Bone, A. Whitford, M.J. Gregory.*)

The strong motion seismograph network in western Canada consists of instruments designed to operate and record ground acceleration only when very strong (1/2% of normal gravity or larger) earth motion occurs. During 1983, three new instrument sites in the Queen Charlotte Islands and one site in northern Vancouver Island were added to this network. In addition, commitments involving four private instrument sites were discontinued. The net number of instruments now consists of 35 accelerographs. (*Contact: H. Bennetts, D.H. Weichert.*)

Routine cataloguing of earthquakes in western Canada continued at PGC. Over the first half of 1983, more than 350 earthquakes were located. (*Contact: R.B. Horner.*)

Special Earthquake Studies

A detailed microearthquake survey was carried out during the summer on the Queen Charlotte Islands in cooperation with the University of British Columbia. Over 250 microearthquakes were recorded, most of them immediately to the west of the Queen Charlotte Islands along the Queen Charlotte fault. Several earthquakes were large enough to be felt by the field party. (*Contact: G.C. Rogers, D.H. Weichert.*)

The expanded telemetered network permitted routine location of microearthquakes within the subducted Juan de Fuca plate 60 to 70 km beneath Georgia Strait and provided the first information on the faulting mechanisms of these deep events. (*Contact: G.C. Rogers.*)

A microearthquake survey was conducted over the IMC potash mine near Esterhazy, Saskatchewan, as part of a joint project with the University of Saskatchewan at Saskatoon to study induced earthquakes. For a period of one week at the end of September, more than 40 microearthquakes were recorded. (*Contact: R.B. Horner.*)

The Beaufort Sea special seismicity study in cooperation with Dome Petroleum was continued through part of the year. The network of five land-based stations is now in reasonable operating condition and should remain in place for another five years. Thoughts about ocean bottom seismometer modifications to allow useful deployment near the seismic cluster are still entertained. (*Contact: D.H. Weichert, G.C. Rogers.*)

Western Canada Seismicity

During 1983, fourteen earthquakes were reported felt in western Canada. These included three on Vancouver Island, four in southern and eastern B.C., two on the Queen Charlotte Islands, three in the Yukon Territory and one in Saskatchewan. The southwest Yukon earthquake on March 30, magnitude 5.4, and the Queen Charlotte event on April 6, magnitude 5.2, were the two largest earthquakes to occur in western Canada during the year. The most widely felt earthquake was centered in Idaho on October 28. This event, magnitude 7.3, caused considerable damage; there were two deaths near the epicentre, and the earthquake was felt throughout the northwestern United States and western Canada from Saskatchewan to British Columbia. No damage was reported in western Canada for any earthquake in 1983. (Contact: R.B. Horner, G.C. Rogers, D.H. Weichert.)

Seismic Risks

A special study of seismic risk was carried out in 1983 in the Queen Charlotte Sound area. Although the point source model used for the whole of Canada is not appropriate here, the necessary additional assumptions on the unknown statistical distributions of dynamical fault source parameters introduce considerable uncertainty. (Contact: D.H. Weichert.)

Gravity



The principal mandate of the Gravity service is to establish the shape of the geoid in Canada to the highest standards and to determine the value of gravity on a regional basis over the Canadian landmass and offshore areas. The regional gravity data provide information for both the determination of crustal structure and the evaluation of resources and are critical to the operation of inertial navigation systems used by defense agencies for submarines and missiles.

Regional land gravity surveys were continued under contract by McElhanney Surveying and Engineering Ltd. Some 850 new gravity stations were observed in an area of northern B.C. covering approximately 180,000 square kilometres. Stations were positioned predominantly on existing geodetic control, however wellsite information as well as information supplied by local agencies was incorporated to achieve the desired 12 kilometre station spacing.

Further work was carried out this year in the Valemont area where approximately

200 gravity stations from the previous year's survey still required positioning. A Litton-2 helicopter-mounted inertial system was provided by the Geodetic Survey of Canada in order to attain the required ± 50 metre horizontal, ± 3 metre vertical control.

An in-house gravity survey also was conducted by helicopter in the Willmore Wilderness Park area, Alberta. Since the park is a wildlife refuge, access in the past has proven difficult thereby creating a void in the national coverage.

The marine component of the gravity program is discussed in the "Multi-parameter—Geophysical Surveys" section. (*Contact: R.P. Riddihough, D.A. Seemann, J.F. Sweeney.*)



Measuring gravity and elevation in Willmore Wilderness Park, Alberta

○ ○ ○ ○ Geothermal Studies ○ ○ ○ ○ ○ ○

The earth's temperature influences both rock properties and geological processes. Thermal data, particularly surface heat flux, are important indicators of deep tectonic processes and the structure of the earth's crust. Most active tectonic processes that result in mountain building, earthquakes and volcanism originate from thermal energy. Geothermal data also are needed to calculate the degree of maturation of hydrocarbons. In addition, the earth has considerable economic potential as a heat source for geothermal energy.

Measured thermal parameters include surface heat flux (the result of vertical temperature gradient multiplied by the thermal conductivity of the rocks), and heat

production from natural radioactive decay in crustal rocks (for example: thorium, uranium and potassium). Studies cover a wide range of geological and geophysical interests—from heat flow, heat production and thermal processes in the deep sea floor, to the discovery and development of geothermal energy resources in western Canada.

Land Studies

There is a continuing program to determine the regional geothermal heat flow pattern from borehole measurements in the Canadian Cordillera. These data can be used in the interpretation of regional tectonics and structure, and in the delineation of hot areas with potential for geothermal energy development. Shallow holes were drilled near the Anahim Volcanic Belt west and east of Wells Gray Park. Initial results indicate that the crust has not been extensively heated when the eruptions occur. (*Contact: T. Lewis, W. Bentkowski.*)

A recent paper by Weichert and Hamilton expressed doubts about the Anahim hotspot hypothesis by correlating recent volcanism and earthquake swarm activity in the 1940s in the western part of the Anahim Volcanic Belt.

A study of the heat flux data available in southern British Columbia, defines the Intermontane and Omineca Crystalline Belts as a heat flow province with a very high reduced heat flux of 63 mWm^{-2} . The best explanation of the level of heat flow is that it is associated with a back-arc convective heat transfer process in the upper mantle. The Insular Belt and western Coast Plutonic Complex are regions of very low heat flux caused by the subduction of oceanic crust beneath them. The transition from low to high heat flux occurs along Jervis Inlet over a distance of 20 km, as defined by oceanic type measurements in the bottom sediments of the fjord. (*Contact: T. Lewis, W. Bentkowski, E.E. Davis.*)

Marine Studies

Offshore, geothermal studies focussed first on the hydrothermal regime of the Juan de Fuca Ridge system. The geothermal compilation of the Juan de Fuca plate map was also completed. Secondly, studies focussed on the heat flow and bathymetry of old ocean basins to put constraints on the aging of the oceanic lithosphere. The old Atlantic program is now being followed by a cruise to one of the oldest parts of the Pacific in the Mariana area. Finally, work is continuing on the thermal regime of the ocean crust using measurements in DSDP crustal boreholes. (*Contact: E.E. Davis, H. Villinger, R.D. Hyndman, T. Lewis.*)

Geomagnetism

The Geomagnetism Field

The earth's geomagnetic field varies both spatially and temporally. This inherent variability is exploited in a variety of ways. To be utilized for navigation, the magnetic field and its gradual change with time must be determined as a function of latitude and longitude. Changes in the magnetic properties of rocks also lead to spatial variations in the magnetic field which become characteristic signatures of structure, composition, and the thermal history of crustal rocks. Short-period temporal changes in the magnetic field must be monitored in order to resolve subtle spatial field variations as encountered in exploration geophysics.

In Canada, the geomagnetic field is monitored continuously at 13 primary observatory sites and discontinuously at about 140 secondary sites. As part of this Canadian Geomagnetic Network, PGC operates the Victoria Geomagnetic Observatory (VGO) on property near the Dominion Astrophysical Observatory.

PGC also collects magnetic field observations at sites in British Columbia. These data are used in updating maps of the geomagnetic field components for the Canadian land mass every 5 years.

Geomagnetic Variations

Temporal variations in the earth's magnetic field provide a source of electromagnetic energy with which to probe the earth's electrical conductivity structure. Because of the relationships to other physical properties, electrical conductivity is an important parameter in understanding the active tectonic regions on the west coast. Deep zones of high conductivity, related to high temperatures and partial melting, determine the maximum thickness of the cold lithosphere riding over the asthenosphere. Conductive zones at shallow depths occur in regions with geothermal resource potential.

The analysis of the geomagnetic variation data obtained at three sites across the transform fault west of Queen Charlotte Sound, reveals a complex three dimensional pattern of electric currents in the region. These electric currents flow along the shelf-slope and in the active segments of the spreading ridge in this area.

The injection of electric current into the seafloor via a vertical cable from a ship produces a magnetic field that can be measured with ocean bottom magnetometers. Two profiles, along Princess Royal and Queen's Reach in Jervis Inlet, provided data that determined the conductivity of the bottom sediments. The result from this first

survey proved the feasibility of the method for seafloor conductivity studies. The development of the controlled-source system is a cooperative project involving the University of Toronto, the Geomagnetic Laboratory (E.P.B., Ottawa) and PGC.

Measurements of the electric field on the seafloor have in the past been difficult because of the high noise level of the electrode sensors. With the development of high sensitivity ring-core fluxgate magnetometers, the electric field could be measured as the vertical gradient between two such sensors. A prototype instrument is currently being designed in collaboration with the University of British Columbia.
(Contact: L.K. Law, J.B. DeLaurier, D.R. Auld.)

Paleomagnetism

The paleomagnetism of rocks records the variations in directions of the geomagnetic field in the geological past. The intensity of the ancient field is also recorded, but is difficult to observe and can only be obtained in very favourable circumstances. The principal application of paleomagnetism is in tectonics—the study of the motion of continents, the opening and closing of oceans and the origin of mountain belts—but it is also used widely in many problems of stratigraphic correlation, the origins and thermal history of rocks, and in the source and origin of magnetic anomalies.

Paleomagnetic work at PGC is concerned with the tectonics of the Cordillera and the western Arctic and magnetostratigraphic studies. During the last decade, geological and geophysical studies have shown that the Cordillera comprises a number of distinct crustal blocks. Vancouver Island is one such block. Paleomagnetic work has shown that these blocks have been transported from the south by distances over 1000 km; much of central British Columbia once being in the latitude of California or beyond. Indeed, Vancouver Island could have moved northward by over 5000 km relative to North America and may have originated on the other side of the Pacific Ocean. The western Cordillera, therefore, appears to be a collage of small crustal fragments that originated elsewhere, were carried over large distances, and finally glued to North America. This discovery has led to a profound revision of ideas about the origin of this and other mountain belts.

Two major programs were initiated. The objective of the first is to collect a suite for a traverse across the Cordillera from Vancouver Island to the Rockies in order to determine the relative latitudes of the various crustal elements at one geological instant in time; namely the Middle Cretaceous epoch near 100 Ma ago. The second program calls for a traverse across the northern rim of the Sverdrup Basin in Ellesmere Island. Results show an unexpected 30° anticlockwise rotation which may reflect strain distributed across northern Ellesmere Island and may be associated with the opening of Baffin Bay. (Contact: E. Irving, P.J. Wynne.)



Arctic Structure and Tectonics



Re-examination of geophysical data from Canada Basin plus borehole and field mapping information from the adjacent continental margin in Canada, suggest that the basin formed in Early and mid-Cretaceous time. The opening process is tentatively divided into two parts: a continental breakup between about 135 and 110 million years ago, and a seafloor formation phase between about 118 and 79 million years ago. (Contact: J.F. Sweeney.)



Geodynamics



The principal subject of geodynamics study in the active region of the west coast of Canada continues to be contemporary crustal deformation. One main objective of this is to establish realistic dynamic models of crustal plate behavior and utilize these in the study of local earthquakes.

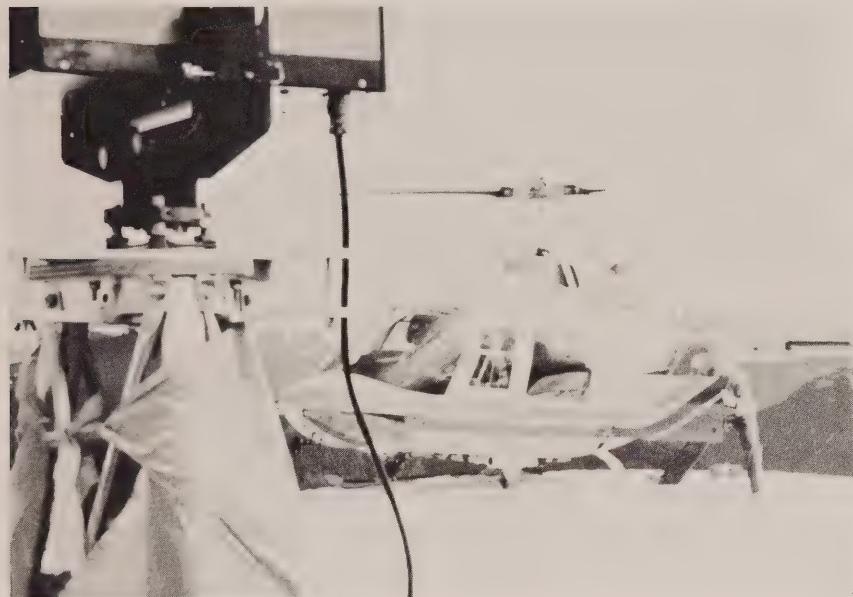
Research in the application of precise gravity measurements in the study of crustal strain continued in two subject areas. In instrumentation research work, an active part was taken in the international calibration campaign for LaCoste and Romberg Model-D gravimeters sponsored by the International Association of Geodesy (IAG). Calibration non-linearities of the Canadian instruments were verified, and these gravimeters can now serve as improved calibration references for other gravimeters. In conjunction with data collection on central Vancouver Island, lake-level monitors have been installed on Buttle Lake to allow *in situ* gravity corrections during the course of the semi-annual precise gravity surveys.

The monitoring of contemporary crustal deformation on central Vancouver Island is also being carried out using vertical and horizontal control surveys. Preliminary levelling results from 1976 and 1982 indicate an apparent relative uplift of about 3 cm in the Campbell River area. This deformation is not directly reflected in the gravity data and may be, in part, an artifact of magnetic field effects on the compensator of self-levelling instruments.

In a cooperative field project with the Department of Geophysics and Astronomy at U.B.C., an additional two of the original sites of the 1947 triangulation network in the Gold River area were tied into the primary horizontal strain network established in 1982. The added data resulted in a revised regional engineering shear strain estimate of 0.30 ustrain units/a with a compressional axis direction between 10 to 20 degrees east of north.

Preparatory work for the measurement of relative crustal deformation over baselines measuring thousands of kilometres using VLBI (Very Long Baseline Interferometry) was also continued. In preparation for occupation by NASA's mobile

radio antenna, a reference monument and a gravel parking pad were installed at DRAO in Penticton. Local horizontal and vertical control networks for monitoring VLBI site stability were established by the Geodetic Survey of Canada at Whitehorse and Yellowknife. (Contact: H. Dragert.)



Two more horizontal control points were recovered from a triangulation network first established in 1947 in the Gold River area. Using laser-ranging instruments and helicopters to measure temperature and humidity along the line-of-sight, distances between mountaintops as great as 50 km can be measured with an accuracy of 1 to 2 cm.

Earth Physics Branch—Technical Support



The technical staff at PGC supported the activities and projects mentioned elsewhere in the PGC review. This included:

The installation of additional seismic telemetry stations at Mt. Grey and Renfrew with a repeater station at Mt. Lazar for the Renfrew station, bringing to four the number of stations now deriving their operating power from solar panels and batteries.

Technical staff also participated, in conjunction with the University of Toronto and the Ottawa EPB technical labs, in the development and operation of a "Controlled Source" system and two high-sensitivity Ocean Bottom Magnetometers (OBMs).

The shipboard "Controlled Source" generates known magnetic fields through the application of controlled electric currents between surface and bottom electrical electrodes. The resultant magnetic fields, modified by the earth's crust, are recorded (utilizing solid-state RAM data storage) on the two high-sensitivity OBM's. This system was successfully used on a one-week cruise on *Vector* in October to Jervis Inlet, and is scheduled for additional inlet work in Bute Inlet and in deep-ocean work from *Endeavor* in 1984.

Successful deployment and recovery of the four PGC Ocean Bottom Seismometers (OBS) was achieved off the east coast of Canada. This was a one-month deployment of the instruments on a cooperative project with Atlantic Geoscience Centre utilizing the ship *CFAV Quest*. Three of the OBSs were recovered on schedule, but the fourth unit was recovered, instrument and data intact, several weeks later on the southern coast of Newfoundland. Work continues in the evolution of 'reliable' release system for ocean-bottom packages, mainly in the areas of electro-magnetic and electrolytic release systems.

The computing system used to gather and analyze the seismic digital data from the West Coast Telemetered Network (WCTN) was expanded. A PDP 11/24 has been added to the existing PDP 11/40 and PDP 11/23s to provide redundancy for real-time data acquisition and expanded capability for graphical data analysis.

The Telemetering Heat Probe (from Applied Microsystems Ltd., Sidney, B.C.) for *in situ* temperature gradient and thermal conductivity measurements of oceanic sediments was operated successfully, including use (without telemetry) on the Arctic CESAR project. Additional work is underway to improve the real-time acoustic telemetry of data from the THP to the surface, and in the application of 'outrigger' thermistors to core barrels for deeper-penetration measurements of temperature gradients.

Five IBM PC and two Hyperion microcomputers were acquired. The two portable Hyperion microcomputers will be used for storage and preliminary reduction of field data in geodynamic and marine magnetic programs. The initial uses for the IBM PCs include 'personal' computing (word processing, spreadsheets, etc.) and use as intelligent terminals to various mainframes for transfer and manipulation of program and data files. Future uses may include the acquisition and preliminary analysis of field data. (*Contact: M.N. Bone, H.J. Bennetts, T.C. Bunyan, H.A. Whitford.*)

APPENDIX I

Contracts Awarded 1983

<i>Development of the XBT/XSV Expendable Bathymeterograph Deck Unit</i>	
A/D Computing Instruments, Victoria, B.C.	\$ 10,000
<i>Development of an Ocean Dumping Control Act</i>	
Edward Anderson Marine Sciences Ltd., Victoria, B.C.	..... 15,000
<i>Study of the Feeding & Activity Patterns of Marine Zooplankton</i>	
Edward Anderson Marine Sciences Ltd., Victoria, B.C.	..... 12,162
<i>Preparation of Final Report on Beaufort Sea Zoobenthos Data</i>	
Arctic Labs Ltd., Sidney, B.C.	..... 26,565
<i>Compilation & Appraisal of Existing Chemical Oceanographic Data from Queen Charlotte Sound, Hecate Strait & Dixon Entrance</i>	
Arctic Laboratories Ltd., Sidney, B.C.	..... 20,568
<i>Compilation of Existing Chemical Oceanographic Data Sets for the Canadian West Coast Offshore Waters, Georgia Strait, Juan de Fuca Strait, Canada Basin and Arctic Ocean</i>	
Arctic Laboratories Ltd., Sidney, B.C.	..... 53,120
<i>Survey of Phytoplankton Distribution in the Southern Beaufort Sea: Remote Sensing in Support of Ecological Studies of the Bowhead Whale</i>	
Arctic Laboratories Ltd., Sidney, B.C.	..... 96,500
<i>Development of Consistent Data Set Rating Scales & Standard Formats for Benthos, Whales, Phytoplankton & Fish</i>	
Arctic Laboratories Ltd., Sidney, B.C.	..... 9,934
<i>Compilation & Appraisal of Existing Chemical Oceanographic Data from the Queen Charlotte Sound, Hecate Strait & Dixon Entrance Areas</i>	
Arctic Laboratories Ltd., Sidney, B.C.	..... 15,050
<i>Development of Techniques for Acoustic Measurement of Directional Ocean Wave Spectra</i>	
Arctic Sciences Ltd., Sidney, B.C.	..... 460,000
<i>Compilation & Appraisal of Existing Physical Oceanographic Data in the Canadian Basin of the Arctic Ocean</i>	
Arctic Sciences Ltd., Sidney, B.C.	..... 39,988
<i>Design Study for a Seabottom-moored Acoustic Wind Velocity System</i>	
Arctic Sciences Ltd., Sidney, B.C.	..... 30,000
<i>Study of Geophysical Regions as Potential Sites for a Detailed Investigation of the Flow Past Ice Keels</i>	
Arctic Sciences Ltd., Sidney, B.C.	..... 6,522
<i>A Study of Current Meter Data Sets for Parry Channel & Adjoining Waterways</i>	
Arctic Sciences Ltd., Sidney, B.C.	..... 12,135
<i>Study of Echo Sounding from High Speed Hydrographic Launches</i>	
Arctic Sciences Ltd., Sidney, B.C.	..... 8,993
<i>Modifications of Primitive Equatrous Model to Study Coastal Cyclogenesis</i>	
Atmospheric Dynamics Corp., Victoria, B.C.	.... 2,105
<i>Determination of Optimum Method of Computing Geostrophic Winds in Parry Channel</i>	
Atmospheric Dynamics Corp., Victoria, B.C.	.... 5,052
<i>Study of Severe Storms in the Beaufort Sea for Tuktoyaktuk Flood Delineation Project</i>	
Atmospheric Dynamics Corp., Victoria, B.C.	.... 7,578
<i>Study of Tangential Wind Stress & Atmospheric Pressure Gradients over the Water for the Coast of B.C.</i>	
Atmospheric Dynamics Corp., Victoria, B.C.	.... 3,579
<i>Investigation of Data Quality for Precipitated Chemistry Project</i>	
L. Benson, Brentwood Bay, B.C.	..... 1,350
<i>Oceanographic Measurement & Analysis of Data on Research Vessel "Charcot"</i>	
G.A. Borstad Ltd., Sidney, B.C.	..... 18,730
<i>Preparation of an Inventory of Prints & Files of 1979 British Columbia Coastal CZCS Imagery</i>	
G.A. Borstad Ltd., Sidney, B.C.	..... 3,030

<i>Ship of Opportunity Sampling of the Planktonic Ecosystem off the Pacific Coast of Canada</i>		<i>Statistical Analysis of Two Large Sediment Data Sets to Provide Minimum Specifications for the Quality Control of Ocean Dumping Analysis</i>
Broccoli Bros., Sidney, B.C.	50,323	Dobrocky Seatech Ltd., North Saanich, B.C. ... 14,000
<i>Sea Testing of Multiple Net Zooplankton Sampling System</i>		<i>Development, Construction & Field Testing of Loran-C Tracked Drogues</i>
Broccoli Bros., Sidney, B.C.	8,437	Dobrocky Seatech Ltd., North Saanich, B.C. ... 205,391
<i>Analysis of Marine Zooplankton Samples</i>		<i>Compilation Review & Assessment of Major Environmental Assessment Reports & Atlases for the West Coast of B.C.</i>
Broccoli Bros., Sidney, B.C.	13,645	Environmental Sciences Ltd., Vancouver, B.C. . 16,548
<i>A Novel Method of Recovery of Lost Mooring Systems from the Seabed</i>		<i>Development of a Discussion Paper on a Method to Initially Evaluate the Environmental Impacts of Proposed Industrial Developments on Marine Mammals & Fish</i>
Brooke Ocean Technology Ltd., Halifax, N.S. ..	75,000	Environmental Sciences Ltd., Vancouver, B.C. . 19,984
<i>Identification, Cataloguing & Disposition of Scientific Collection</i>		<i>Development of Predictive Basis for Mysid & Euphausiid Fishery Utilisation & Management</i>
K. Bruce, Sidney, B.C.	11,000	E.V.S. Consultants Ltd., North Saanich, B.C. ... 73,865
<i>Testing of Techniques to be Applied to Re-inforcing Photovoltaic Modules for Marine Application</i>		<i>Study Effects of Wood Waste on the Recruitment of Marine MacroBenthos</i>
Cantech Scientific Instruments Ltd., North Saanich, B.C.	500	E.V.S. Consultants Ltd., North Saanich, B.C. ... 15,258
<i>Numerical Modelling of Shallow Water Kinematic Diffusive Waves on the West Coast of Canada</i>		<i>Development of a Programme of a Finite Difference Shallow Water Model of the Dixon Entrance-Hecate Strait-Queen Charlotte Sound</i>
CPRO Computing Enterprises, Victoria, B.C. ..	37,697	M.G. Gatien, Sidney, B.C. 4,800
<i>Calculation of Extent of Inundation at Tuktoyaktuk Due to Storm Surges</i>		<i>Compilation & Correlation of Oceanographic Data in the Lower Fraser River</i>
C PRO Computing Enterprises, Victoria, B.C. ...	5,400	A. Hartley, Victoria, B.C. 4,500
<i>Development of Irregular Grid Model of Northwest Passage</i>		<i>Investigation of Arctic Industrial Offshore Activities & Ocean Dredging & Dumping in B.C. Coastal Waters</i>
C PRO Computing Enterprises, Victoria, B.C. ...	31,544	R.H. Herlinveaux, North Saanich, B.C. 10,000
<i>Collection of Hydrographic Field Data for Correcting & Updating Navigational Charts, Sailing Directions & Tidal Publications</i>		<i>Technical Review & Oceanographic Assessment of Selected Industrial Proposals</i>
Coast Pilot Ltd., Sidney, B.C.	97,535	R.H. Herlinveaux 10,000
<i>Taxonomy of Haplotaixidae</i>		<i>Development of Instrumented Oceanographic Moorings</i>
K. Coates, Saanichton, B.C.	1,995	A. Hofland, Sidney, B.C. 2,480
<i>Literature Review of Theoretical & Experimental Work on Acoustic Scattering from Turbulence, Microstructure & Biological Targets in the Pacific Ocean</i>		<i>Oceanographic Support for the West Coast of the Queen Charlotte's Survey</i>
G. Crawford, Victoria, B.C.	2,500	A. Hofland, Sidney, B.C. 2,940
<i>Study to Develop the Relationship Between Sound Scattering Temperature and Velocity</i>		<i>Computer Programming of a Finite-differential Model of the N.W. Passage</i>
G. Crawford, Victoria, B.C.	2,000	K. Holtham, Victoria, B.C. 3,248
<i>Study of Metal Binding Proteins in Marine Invertebrates</i>		
Dobrocky Seatech Ltd., North Saanich, B.C. ...	7,374	

<i>Preparation of an Oceanographic Hydrographic Audio-Visual Text for a Department of Fisheries & Oceans Display</i>		<i>Data Compilation & Appraisal of Beaufort Sea Whales</i>	
Hoot Productions, Victoria, B.C.	6,500	L.G.L. Ltd., Sidney, B.C.	8,855
<i>Development of Theory & Analysis of Operation of an Echometer for the Remote Detection of Sound</i>		<i>Preparation of Detailed Plans to Complete the Development & Testing of the Correlation Sonar Profiling Current Meter</i>	
D. Huston, Sidney, B.C.	3,948	J.F. Mattock, Edmonton, Alberta	10,000
<i>Development & Evaluation of Methods for Simulating Langrangian Trajectories in Geostrophic Turbulence</i>		<i>Bioaccumulation Studies on Bivalves Exposed to Kitsault Mine Tailings</i>	
Interact Computing Services Ltd., Sidney, B.C. .	7,840	D. McLeay & Associates Ltd., West Vancouver, B.C.	57,860
<i>Computed Heat Flux Statistics for the North Pacific Based on Transpac XBT Data</i>		<i>To Modify G & H Series MSI Digitisers</i>	
Interact Computing Services Ltd., Sidney, B.C. .	7,810	Meyer Systems Inc., Vancouver, B.C.	20,000
<i>Preparation of Charts of Tides & Currents in the Great Barrier Reef of the Coral Sea</i>		<i>Preparation of Line Drawings for Scientific Publication</i>	
Interact Computing Services Ltd., Sidney, B.C. .	2,458	McSorley Illustration & Design, Victoria, B.C. .	1,912
<i>Programming of Inverse Method Calculations for Tides in the N.W. Passage</i>		<i>Preparation of an Operational Manual on the Application of Automated Metrolm #636 Titroprocessor to Seawater Samples</i>	
Interact Computing Services Ltd., Sidney, B.C.	11,167	H. Neville, Victoria, B.C.	11,025
<i>Development & Application of Computer Programmes to Process & Analyse Oceanographic Data</i>		<i>Tsunami Data Computer Programming</i>	
Interact Computing Services Ltd., Sidney, B.C. .	20,755	M.M. Nugent, Victoria, B.C.	4,200
<i>Parameter Dependence Survey of Large Scale Transport of Tracer Substance by Eddies</i>		<i>Analysis of Data from FGGE Drifting Buoy Arrays</i>	
Interact Computing Services Ltd., Sidney, B.C. .	9,597	Odysseas Ocean Sciences Ltd., North Saanich, B.C.	24,975
<i>Collection & Analyses of Samples from Moored Sediment Trap & Hydrocasts at Ocean Station P</i>		<i>Analysis of FGGE Buoy Drifters</i>	
Iseki Environmental Research, Central Saanich, B.C.	8,764	Odysseas Ocean Sciences Ltd., North Saanich, B.C.	9,805
<i>Analysis of Deep Sea Sediment Samples & Report on Analytical Procedures for Deep Sea Particulate Organic Carbon</i>		<i>Video Tape Documentation of Sterntow</i>	
ISK Environmental Research, Central Saanich, B.C.	3,568	Pacific Sea Life Data Inc., Victoria, B.C.	10,000
<i>Analysis of Sea Surface Conditions by Long Range Sound Propagation</i>		<i>Data Interception of Ships of Opportunity</i>	
Jasco Research Ltd., Victoria, B.C.	6,000	D. Philip, Vancouver, B.C.	3,150
<i>Design & Deployment of Oceanographic Mooring System off West Coast of Queen Charlotte Islands</i>		<i>Analysis of Tsunami Potential of Landslides</i>	
T. Juhasz, Victoria, B.C.	60,375	D. Philip, Victoria, B.C.	2,550
<i>Fabrication & Programming of Aanderaa Data Translator</i>		<i>Investigation of Methods Currently Employed to Obtain Ice Thickness Distribution</i>	
E. Koome, Victoria, B.C.	5,400	Polar Tech Ltd., North Saanich, B.C.	3,700
<i>Compilation & Collation of Tsunami Records</i>		<i>Development of an Electrical Power Generator to Drive Useful Energy from Salinity Gradients through Application of Reverse Electro-Dialysis Techniques</i>	
M. Lane, Victoria, B.C.	3,200	RETECH—Capital Applied Research & Technology Ltd., Victoria, B.C.	59,990
		<i>Study the Processes Contributing to the Momentum Exchanges between Moving Ice Cover and the Underlying Ocean</i>	
		Dr. R.D. Rowe, Calgary, Alberta	19,870

<i>Oceanographic Data Collection of the Coastal Waters of B.C.</i>	S & B Research Ltd., North Saanich, B.C.	14,991	<i>Documentation of Acoustic System from Coastal Zone Oceanography Field Trials</i>	Sy Tech Research Ltd., North Saanich, B.C.	1,200
<i>Co-ordination & Interpretation of Precipitation Chemistry Data</i>	S & B Research Ltd., North Saanich, B.C.	10,304	<i>Compile an Inventory List for Engineering Services</i>	Sy Tech Research Ltd., North Saanich, B.C.	2,025
<i>Compilation, Processing & Interpretation of Marine Meteorological Data</i>	S & B Research Ltd., North Saanich, B.C.	10,080	<i>Design, Fabricate & Test Electronic Circuits for the Echometer Project Phase II</i>	Sy Tech Research Ltd., North Saanich, B.C.	15,540
<i>Analysis of Sea Water Samples</i>	Seakem Oceanography Ltd., Sidney, B.C.	5,621	<i>Design, Fabricate, Test Electric Circuits</i>	Sy Tech Research Ltd., North Saanich, B.C.	20,607
<i>Analysis of Dissolved Nutrients in Sea Water</i>	Seakem Oceanography Ltd., Sidney, B.C.	8,294	<i>Preparation of Draft Diagrams for El Nino Seminar</i>	I. Szabo, Sidney, B.C.	1,100
<i>Analysis of Trace Metals using Ultra Clean Room & Mass Spectrometry</i>	Seakem Oceanography Ltd., Sidney, B.C.	37,402	<i>Development of Shallow Water Hydrographic Survey Techniques Using a Fixed Wing Float Plane</i>	Terra Surveys Ltd., North Saanich, B.C.	42,250
<i>Development, Construction, Test of Correlation Sonar Meter Shipboard & Ocean Bottom Mounted Prototype Systems Phase III & IV</i>	Seakem Oceanography Ltd., Sidney, B.C.	404,000	<i>Seamark II High Resolution Swath Bathymetry & Acoustic Sidescan of Northern Juan de Fuca Ridge System and Vancouver Island Continental Slope</i>	University of Hawaii, U.S.A.	390,000
<i>Analysis of Sea Water Samples</i>	Seakem Oceanography Ltd., Sidney, B.C.	5,621	<i>Numerical Modelling Studies of the Estuarine Circulation in the Strait of Georgia, Part V</i>	Dr. Burling, University of B.C., Vancouver, B.C.	24,000
<i>Analysis of Marine Air Samples from Land Stations and Other Cruises</i>	Seakem Oceanography Ltd., Sidney, B.C.	40,000	<i>Development of A Fibre Optic Acoustic Detector</i>	Dr. Branston, University of Victoria, B.C.	12,603
<i>Oceanographic Observations Aboard CSS Parizeau</i>	Soliton, Sidney, B.C.	1,540	<i>Develop a "Head Space" Technique to Investigate Air-Sea Transfer of Freon</i>	Prof. McAuley, University of Victoria, B.C.	7,500
<i>Compilation & Collation of Tsunami Records</i>	P. Straub, Sidney, B.C.	1,800	<i>Development of A Remote L/R Indicator for Field Hydrography</i>	Walker Industrial Computing Ltd., North Saanich, B.C.	5,670
<i>Mobilisation of Equipment & Technical Support for Ocean Turbulence Measurements</i>	Sy Tech Research Ltd., North Saanich, B.C.	4,760	<i>Development of Scientific Tools for Pisces IV</i>	Witney, MacInnis Engineering Ltd., Lions Bay, B.C.	64,100

APPENDIX II

Publications

A. Department of Fisheries and Oceans

(1) Canadian Data Report of Hydrography and Ocean Sciences

No. 5 Volume 3	Birch, J.R., D.B. Fissel, D.D. Lemon, A.B. Cornford, R.A. Lake, B.D. Smiley, R.W. Macdonald and R.H. Herlinveaux	<i>Arctic Data Compilation and Appraisal. Northwest Passage: Physical Oceanography—Temperature, Salinity Currents and Water Levels</i>
No. 5 Volume 4	Thomas, D.J., R.W. Macdonald, A.G. Francis, V. Wood and A.B. Cornford	<i>Arctic Data Compilation and Appraisal. Northwest Passage: Chemical Oceanography</i>
No. 5 Volume 5	Birch, J.R., D.B. Fissel, D.D. Lemon, A.B. Cornford R.H. Herlinveaux, R.A. Lake and B.D. Smiley	<i>Arctic Data Compilation and Appraisal. Baffin Bay: Physical Oceanography—Temperature, Salinity, Currents and Water Levels</i>
No. 5 Volume 6	Fissel, D.B., L. Cuypers, D.D. Lemon, J.R. Birch, A.B. Cornford, R.A. Lake, B.D. Smiley, R.W. Macdonald and R.H. Herlinveaux	<i>Arctic Data Compilation and Appraisal. Queen Elizabeth Islands: Physical Oceanography— Temperature, Salinity, Currents and Water Levels</i>
No. 7	Freeland, H.J.	<i>Low Frequency Currents Observed off Southern Vancouver Island, 1979-1981</i>
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Stucchi *Alberni Inlet CTD Data Report, 1979-1981*

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- No. 18 Macdonald, R.W. (ed.) *Proceedings of a Workshop on the Kitimat Marine Environment*
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Brinkhurst, R.E. Woods
and D.C. Jeffries *Benthic Studies in Alice Arm and Hastings Arm, B.C.
in Relation to Mine Tailings Dispersal*
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D.J. Stucchi *An Analysis of the Alice Arm Crash Program Data—Summer 1981*
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(3) Canadian Contractor Report of Hydrography and Ocean Sciences

- No. 8 Ford, L. and M. Nicoll *Oceanographic Observations in Alice Arm, B.C., May 1981*
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Individual CTD Casts*

No. 11	Woods, S.M. and S.C. Byers (eds.)	<i>Report on Ocean Dumping R&D Pacific Region, Department of Fisheries and Oceans 1981-1982</i>
No. 14	May, G.A.	<i>Correlation Sonar Using Pseudo-Random Noise Codes</i>

(4) Other Publications, 1983

- BAKER, H.R. 1982. To new Phalodriline genera of marine Oligochaeta (Annelida; Tubificidae) from the Pacific northeast. *Can. J. Zool.*, **60**: 2487-2500.
- BAKER, H.R. 1982. *Vadicola aprostatus* nov. gen. nov. spec., a marine oligochaete (Tubificidae; Rhyacodrilinae) from British Columbia. *Can. J. Zool.*, **60**: 3232-3236.
- BAKER, H.R. 1983. New species of *Tubificoides* Lastockin (Oligochaeta; Tubificidae) from the Pacific northeast and the Arctic. *Can. J. Zool.*, **61**: 1270-1283.
- BAKER, H.R. 1983. New species of *Bathydrilus* Cook (Oligochaeta; Tubificidae) from British Columbia. *Can. J. Zool.*, **61**: 2162-2167.
- BELL, W.H. 1983. Turbulence vs drag—some further considerations. *Ocean Engineering*, Vol. 10(1): 47-63.
- BENNETT, A.F. 1983. The South Pacific including the East Australian Current. In: *Eddies in Marine Science*, A.R. Robinson (ed.), Springer-Verlag, 219-344.
- BENNETT, A.F. and L.M. LESLIE. Statistical correction of dynamical prognoses: the decision problem. *Monthly Weather Review*, **111**: 344-352.
- BENNETT, A.F. and D.B. HAIDVOGEL. 1983. Low-resolution numerical simulation of decaying two-dimensional turbulence. *Journal of the Atmospheric Sciences*, **40**: 738-747.
- BENNETT, A.F. and K.J.F. MIDDLETON. 1983. Statistical mechanics of a finite-difference approximation to the barotropic vorticity equation. *Quarterly Journal, Royal Meteorological Society*, **109**.
- BENNETT, A.F. 1983. Predictability and frontogenesis. In: *Predictability of Fluid Motions*, G. Holloway and B.J. West (eds.), American Institute of Physics, New York.
- BRINKHURST, R.O. 1983. Coastal ecology: an essay on practical approaches in coastal zone management in British Columbia, B. Sadler (ed.). *Cornett Occasional Papers*, **3**: 53-64.
- BRINKHURST, R.O. 1983. Book review of *Coastal Research in the Gulf of Bothnia*. *Can. J. Fish. Aquat. Sci.*, **39**: 253.
- BRINKHURST, R.O., P.M. CHAPMAN and M.A. FARRELL. 1983. A comparative study of respiration rates of some aquatic oligochaetes in relation to sublethal stress. *Int. Rev. ges. Hydrobiol.*, **68**: 683-699.
- BRINKHURST, R.O. and R.D. KATHMAN. 1983. A contribution to the taxonomy of the Naididae (Oligochaeta) of North America. *Can. J. Zool.*, **61**.

- BRINKHURST, R.O. and R.D. KATHMAN. 1983. *Varichaetadrilus*, a new name for *Varichaeta* Brinkhurst, 1981 *non* Speiser, 1903 (Diptera) with a description of a new species *V. fulleri*. *Proc. Biol. Soc. Wash.* **96**: 301-306.
- BRINKHURST, R.O. and R.D. KATHMAN. 1983. *Arctodrilus wulikensis* new genus new species (Oligochaeta; Tubificidae) from Alaska. *Proc. Biol. Soc., Wash.* **96**: 407-410.
- CARNEVALE, G.F. and G. HOLLOWAY. 1982. Information decay and the predictability of turbulent flows. *Journal of Fluid Mechanics*, **116**: 115-121.
- CLIFFORD, S.F. and D.M. FARMER. 1983. Ocean flow measurements using acoustic scintillation. *J. Acoust. Soc. Am.*, **74**(6): 1826-1832.
- CORNFORD, A.B. and R.W. MACDONALD. 1983. Scientific evaluation of marine disposal of False Creek sediments pertinent to the Ocean Dumping Act and the Fisheries Act, 15 pp.
- COSSON, R.P. and J.A.J. THOMPSON. 1983. Utilisation de l'électrode PAR 303 pour la détection et le dosage des métallothionéines dans les tissus d'invertébrés marins. *Analisis*, **11**: 33-35.
- CRAWFORD, W.R., R.E. THOMSON and W.S. HUGGETT. 1983. Continental shelf waves of diurnal period along Vancouver Island. In: *Coastal Oceanography*, H. Gade, A. Edwards and H. Svendsen (eds.), Plenum Press, 225-234.
- CRAWFORD, W.R. 1983. Energy flux and generation of shelf waves along Vancouver Island. *J. Phys. Oceanogr.*
- CREAN, P.B., M. BOLTON, W.S. HUGGETT. *Atlas of Currents: Juan de Fuca Strait and Strait of Georgia*. Canadian Hydrographic Service, Department of Fisheries and Oceans, Ottawa.
- CREAN, P.B. 1983. A numerical approach to simulating the estuarine circulation in a strongly tidal deep coastal sea between Vancouver Island and the mainland. In: *Proceedings of the 3rd International Conference on Applied Mathematical Modelling*, Mitteilungen Des Institut für Meereskunde der Universität Hamburg, No. 26.
- CRETNEY, W.J., C.S. WONG, R.W. MACDONALD, P.E. ERICKSON and B.R. FOWLER. 1983. Polycyclic aromatic hydrocarbons in surface sediments and age dated cores from Kitimat Arm, Douglas Channel and adjoining waterways. *Can. Tech. Rep. Hydrogr. Oc. Sci.*, **18**: 162-196.
- DENHARTOG, G., S.D. SMITH, R.J. ANDERSON, D.R. TOPHAM and R.G. PERKIN. 1983. An investigation of a polynya in the Canadian archipelago. III, Surface heat flux. *J. Geo. Res.*, **88** (C5).
- DENMAN, K.L. 1983. Predictability of the marine planktonic ecosystem. In: *Predictability of Fluid Motions*, G. Holloway and B.J. West (eds.), Am. Institute of Physics, New York, 570-572.
- DENMAN, K.L. and A.E. GARGETT. 1983. Time and space scales of vertical mixing and advection of phytoplankton in the upper ocean. *Limnology and Oceanography*, **28**: 801-815.
- DWORSKI, J.G. and G. HOLLOWAY. 1983. Statistical representations of seafloor topography. *Univ. of Washington, Special Report No. 94*.

- ERSEUS, C. and H.R. BAKER. 1982. New species of the gutless marine genus *Inanidrilus* (Oligochaeta; Tubificidae) from the Gulf of Mexico and Barbados. *Can. J. Zool.*, **60**: 3063-3067.
- FARMER, D.M. and H.J. FREELAND. 1983. The physical oceanography of fjords. *Progress in Oceanography*, **12**(2): 147-220.
- FARMER, D.M. and G.B. CRAWFORD 1983. Measurements of acoustic correlation in the ocean with a high frequency echo-sounder. *Nature*, **301**, No. 5902, 698-700.
- FARMER, D.M. Stratified flow over sills. 1983. In: *Coastal Oceanography*, H. Gade, A. Edwards and H. Svenden (eds.), Plenum Press, 337-362.
- FARROW, G.E., J.P. SYVITSKI and V. TUNNICLIFFE. 1983. Suspended particulate loading on the macrobenthos in a highly turbid fjord, Knight Inlet, B.C. *Can. J. Fish. Aquat. Sci.*, **40**: 273-288.
- FILLMORE, S. and R.W. SANDILANDS. *The Chartmakers—A History of Nautical Surveying in Canada*, NC Press, Toronto, 255 pp.
- FOREMAN, M.G.G. 1983. An analysis of two-step time discretizations in the solution of the linearized shallow water equations. *Journal of Computational Physics*, Vol. 51, No. 3, 454-483.
- FOREMAN, M.G.G. An analysis of the wave equation model for finite element tidal computations. *Journal of Computational Physics*, Vol. 52, No. 1, 290-312.
- FREELAND, H.J. 1983. A seasonal upwelling event observed off the west coast of British Columbia, Canada. In: *Coastal Oceanography*, H. Gade, A. Edwards and H. Svenden (eds.), Plenum Press, N.Y., 217-223.
- FREELAND, H.J. 1983. Book review of *Descriptive Physical Oceanography* by Pickard and Emery. *Can. J. Fish. Aquat. Sci.*, **40**(3): 385.
- FREELAND, H.J., W.R. CRAWFORD and R.E. THOMSON. 1983. Currents along the Pacific coast of Canada. *Atmosphere-Ocean*. In press.
- GOWER, J.F.R. 1983. "Layover" in satellite radar images of ocean waves. *J. Geophys. Res.*, **88**: 7719-7720.
- GOWER, J.F.R. 1983. Water colour imaging from space. Paper presented at the *15th International Liege Colloquium on Ocean Hydrodynamics*, May 1983.
- HAIDVOGEL, D.B. and G. HOLLOWAY. 1983. Predictability: Lagrangian and Eulerian views. In: *Predictability of Fluid Motions*, Amer. Inst. of Physics, 67-68.
- HOLLOWAY, G. 1982. On interaction time scales for oceanic internal waves. *J. Physical Oceanography*, **12**: 293-296.
- HOLLOWAY, G. 1982. Theories of the oceanic internal wave environment. *Technical Report PD-NW-80-244R, Physical Dynamics Inc.*, Bellevue, Washington, 83 pp.

- HOLLOWAY, G. 1982. A comment on streakiness. *Ocean Modelling*, No. 43.
- HOLLOWAY, G. 1983. Effects of planetary wave propagation and finite depth on the predictability of atmospheres. *J. Atmos. Sci.*, **40**: 314-327.
- HOLLOWAY, G. 1983. A conjecture relating oceanic internal waves and small scale processes. *Atmos-Ocean*, **21**: 107-122.
- HOLLOWAY, G. 1983. Contribute to: *Dispersal from Ocean Sources: Physical and Related Scientific Processes*, A.R. Robinson and S.L. Kupferman (eds.), *Sandia National Laboratory Report*, to appear, 212 pp.
- HOLLOWAY, G. and B.J. WEST. (Eds.). (c1983) *Predictability of Fluid Motions*. Amer. Inst. of Physics, 604 pp.
- HOLLOWAY, G. 1983. Contrary roles of planetary wave propagation in atmospheric predictability. In: *Predictability of Fluid Motions*, 593-600.
- HUGGETT, W.S. and S.O. WIGEN. 1983. Surface currents in the approaches to Kitimat. *Can. Tech. Rep. Hydrogr. Oc. Sci.*, **18**: 34-64.
- HUGHES, B.A. and J.F.R. GOWER. 1983. SAR imagery and surface truth comparisons of internal waves in Georgia Strait, British Columbia, Canada. *J. Geophys. Res.*, **88**: 1809-1824.
- JOHNSON, W.K. and C.S. WONG. 1983. Manual for mercury analysis of sea water at Ocean Chemistry Division. *Ocean Chem. Project Rep.*, 29 pp.
- LEVINGS, C.D., R.E. FOREMAN and V. TUNNICLIFFE. 1983. Review of the benthos of the Strait of Georgia and contiguous fjords. *Can. J. Fish. Aquat. Sci.*, **40**: 1120-1141.
- LEWIS, E.L. and R.G. PERKIN. 1983. Supercooling and energy exchange near the Arctic Ocean surface. *J. Geophys. Res.*, **88**(C12): 7681-7685.
- LIN, S., G.A. BORSTAD and J.F.R. GOWER. 1983. Remote sensing of chlorophyll in the red spectral region. Paper presented at the *15th International Liege Colloquium on Ocean Hydrodynamics*, May 1983.
- LITHERLAND, J. and G. HOLLOWAY. Statistical theory of the predictability of equivalent barotropic motion on a beta plane. In: *Predictability of Fluid Motions*, 333-348.
- LUECK, R.G., W.R. CRAWFORD and T.R. OSBORN. 1983. Turbulent dissipation over the continental slope off Vancouver Island. *J. Phys. Oceanogr.* In press.
- MACDONALD, R.W., D.M. MACDONALD and C.S. WONG. 1983. Manual for the determination of Pb-210 at Ocean Chemistry Division. *Ocean Chem. Project Rep.*, 29 pp.
- MACDONALD, R.W., M. O'BRIEN, D.M. MACDONALD and V. SCOTT. 1983. A manual for the determination of particulates in sea water by filtration at Ocean Chemistry, 11 pp.

- MACDONALD, R.W., B.D. BORNHOLD and I. WEBSTER. 1983. The Kitimat fjord system, an introduction. *Can. Tech. Rep. Hydrogr. Oc. Sci.*, **18**: 2-14.
- MACDONALD, R.W., W.J. CRETNEY, C.S. WONG and P. ERICKSON. 1983. Chemical characteristics and water in the Kitimat fjord system. *Can. Tech. Rep. Hydrogr. Oc. Sci.*: **18**, 66-88.
- MACDONALD, R.W. 1983. The distribution and dynamics of suspended particles in the Kitimat fjord system. *Can. Tech. Rep. Hydrogr. Oc. Sci.*, **18**: 116-138.
- MACDONALD, R.W. and D.J. THOMAS. 1983. Assessing environmentally acceptable levels of metals in drilling products: The Beaufort Sea as a case study. In: *Proceedings of the 12th Annual Arctic Environmental Workshop, Issues of the 80s*, 137-156.
- MURTY, T.S. Boundary integral solutions for water wave problems. *Journal of Hydraulic Engineering*, Amer. Soc. of Civil Engineers, Vol. 109, No. 6, 939-940.
- MURTY, T.S. and R.F. HENRY. Tides in the Bay of Bengal. *J. Geophys. Res.*, **88**(C10): 6069-6076.
- MURTY, T.S., G.A. MCBEAN and B. MCKEE. Explosive cyclogenesis over the northeast Pacific Ocean. *Monthl Weather Review*, Vol. III, No. 5, 1131-1135.
- MURTY, T.S. Sunspot activity and tsunamis in the Pacific Ocean. *Lighthouse*, No. 27, 31-32.
- MURTY, T.S. Meteorology and oceanography in the Falkland Islands region. *Lighthouse*, No. 26, 10-13.
- MURTY, T.S. Storm surges and tsunamis on the coastlines of Canada. In: *Proceedings of the Canadian Coastal Conference—83*, Vancouver, B.J. Holden (ed.), published by the Associate Committee for Research on Shoreline Erosion and Sedimentation, N.R.C., Ottawa, 135-148.
- MURTY, T.S. Book review of *Identification of Seismic Sources—Earthquake or Underground Explosion*, E.S. Husebye and S. Mykkeltveit (eds.), D. Reidel Publishing Co., Dordrecht. In: *Marine Geodesy*, Vol. 6, Nos. 3-4, 343-344.
- MURTY, T.S. Book review of *Current Research in Earthquake Prediction*, T. Rikitake (ed.), D. Reidel Publishing Co. Tokyo. In: *Marine Geodesy*, Vol. 6, Nos. 3-4, 345-346.
- MURTY, T.S. Book review of *The Sea Floor: An Introduction To Marine Geology*, by E. Seibold and W.H. Berger, Springer-Verlag, Berlin. In: *Marine Geodesy*, Vol. 6, Nos. 3-4, p. 353.
- ORTNER, P.B., R.E. PIEPER and D.L. MACKAS. 1983. Advances in zooplankton sampling. In: *Report on Fish Ecology III—A Foundation for a Recruitment Experiment*, B. Rothschild and C. Rooth (eds.), University of Miami Press, 355-380.
- SANDILANDS, R.W. 1983. Vignettes from hydrography's past. In: *Proc. Centennial Conf. Canadian Hydrographic Service 1983*, Ottawa, April 5-8, 1983. Can. Special Publication of Fisheries and Aquatic Sciences 67, 36-41.
- SANDILANDS, R.W. Hydrographic surveying in the Great Lakes during the nineteenth century. *International Hydrographic Review*, Monaco, LX(2), July 1983. (Reprinted from the Canadian Surveyor.)

- SEKI, H., F.A. WHITNEY and C.S. WONG. 1983. Copper effects on dynamics of organic materials in marine controlled ecosystems. *Arch. Hydrobiol.*, **96**: 176-189.
- SHEN, C. and G. HOLLOWAY. 1982. Spectral formulation of internal wave interaction. *Technical Report No. 392, School of Oceanography, University of Washington*, 36 pp.
- SMITH, S.D., R.J. ANDERSON, G. DENHARTOG, D.R. TOPHAM and R.G. PERKIN. An investigation of a polynya in the Canadian archipelago—II, Structure of turbulence and sensible heat flux. *J. Geo. Res.*, **88**(C5).
- STUCCHI, D.J. 1983. Shelf-fjord exchange on the west coast of Vancouver Island. In: *Coastal Oceanography*, H. Gade, A. Edwards and H. Svenden (eds.), NATO Conf. Ser., Marine Sciences Ser. IV, Plenum Press, 439-450.
- STUCCHI, D.J. and L.F. GIOVANDO. 1983. Deep water renewal in Saanich Inlet, B.C. In: *Oceanography of an Intermittently Anoxic Fjord*, S.K. Juniper and R.O. Brinkhurst (eds.). In press.
- STUKAS, V.J. and C.S. WONG. 1983. Accurate and precise analysis of trace levels of Cu, Cd, Pb, Zn, Fe and Ni in sea water by isotope dilution mass spectrometry. In: *Trace Metals in Sea Water*, C.S. Wong et al (eds.), Plenum Press, N.Y., 513-536.
- STUKAS, V.J. and C.S. WONG. 1983. Application of isotope dilution mass spectrometry to the determination of Cu, Cd, Pb, Zn, Fe and Cr in sea water. *Marine Chemistry*, **12**: 133-146.
- TABATA, S. 1983. Interannual variability in the abiotic environment of the Bering Sea and the Gulf of Alaska. In: "From Year to Year", *Interannual Variability of the Environment and Fisheries of the Gulf of Alaska and the Eastern Bering Sea*, W.S. Wooster (ed.), A Washington Sea Grant Publication, University of Washington, 139-145.
- TABATA, S. 1983. Accuracy of NOAA-7 observed SST in the northeast Pacific Ocean. Presented at *Jet Propulsion Lab., Cal. Inst. Tech.*, 9 pp.
- TABATA, S. 1983. Oceanographic conditions off the Pacific coast of Canada during the 1982-1983 El Nino. Presented at the *8th Climate Diagnostic Workshop*, (NOAA and AES), 22 pp.
- TABATA, S. 1983. Influence of ocean conditions on the production of salmonids. Presented at the *Cooperative Institute for Marine Resource Studies, Oregon State University*, 50 pp.
- THOMSON, R.E. 1983. A comparison between computed and measured oceanic winds near the British Columbia coast. *J. Geophys. Res.*, **88**: 2675-2683.
- THOMSON, R.E. 1983. Physical oceanographic aspects of coastal British Columbia. In: *Coastal Zone Management in British Columbia*, Barry Sadler (ed.), Cornett Occasional Papers, No. 3, 7-27.
- THOMSON, R.E. Book review of *Hydrodynamic Instabilities, and the Transition to Turbulence*, H.L. Swinney, and J.P. Gollub (eds.), Springer-Verlag, Berlin. In: *Marine Geodesy*, Vol. 6, No. 2, 190 pp.

- THOMSON, R.E. 1983. El Nino: An equitorial phenomenon of global importance. Presented at *DFO Field Services Branch Annual Meeting*, November, 1983.
- TOPHAM, D.R., R.G. PERKIN, S.D. SMITH, R.J. ANDERSON and G. DENHARTOG. An investigation of a polynya in the Canadian archipelago — I, Introduction and oceanography. *J. Geophys. Res.*, **88**(C5).
- TUNNICLIFFE, V., R.L. CHASE, G.E. FARROW and D. NELSON. 1983. Rocks, sediments and benthos of Cobb Seamount, northeast Pacific Ocean. *Geol. Assoc. Can., Abstr.* v. 8, p. A70.
- TUNNICLIFFE, V. and J.P. SYVITSKI. 1983. Corals move boulders: an unusual mechanism of sediment transport. *Limnol. Oceanogr.*, **28**: 564-568.
- WOLANSKI, E. and A.F. BENNETT. Continental shelf waves and their influence on the circulation around the Great Barrier Reef. *Australian Journal of Marine and Freshwater Research*. **34**: 23-47.
- WOLANSKI, E. and R.E. THOMSON. 1983. Wind-driven circulation on the northern Great Barrier Reef continental shelf in summer. *J. Estuarine Coast. Marine Sci.* In press.
- WONG, C.S., E.A. BOYLE, K.W. BRULAND, J.D. BURTON and E.D. GOLDBERG (eds.). 1983. *Trace Metals in Sea Water. Proceedings of a NATO Advanced Research Institute* held in Erice, Italy, March 30 - April 5, 1983, Plenum Press, N.Y., 891 pp.
- WONG, C.S., K. KREMLING, J.P. RILEY, W.K. JOHNSON, V. STUKAS, P.G. BERRANG, P. ERICKSON, D. THOMAS, H. PETERSON and B. IMBER. 1983. Intercomparison of sampling devices and analytical techniques using sea water from a CEPEX enclosure. In: *Trace Metals in Sea Water*, C.S. Wong et al (eds.), Plenum Press, N.Y., 175-193.

B. Department of the Environment

- MCBEAN, G.A. Boundary layer structure over the ocean. Paper presented at *CMOS Conference*, Banff, Alberta, May 1983.
- MCBEAN, G.A. Precipitation chemistry in Pacific coastal regions. Paper presented at *CMOS Conference*, Banff, Alberta, May 1983.
- VERMEER, K., I. ROBERTSON, R.W. CAMPBELL, G. KAISER and M. LEMON. 1983. Distribution and densities of marine birds on the Canadian west coast. *Can. Wildlife Serv. Report*, Vancouver, B.C., 73 pp.
- VERMEER, K. 1983. Comparison of the diet of the Glaucous-winged Gull on the east and west coasts of Vancouver Island. *Murrelet*, **63**: 80-85.
- VERMEER, K. 1983. Diet of the Harlequin Duck in the Strait of Georgia, British Columbia. *Murrelet*, **64**: 54-57.

C. Department of Energy, Mines and Resources

- BECKER, M., H. DRAGERT, E. KANNGIESER, A. LAMBERT, J. MAKINEN, B. RICHTER and D. WOODWARD. 1983. Report on High-Precision Gravimetry—Volume II. *Report to IAG by Special Study Group 3.37*, E. Groton (ed.), *Informations on Cartography and Geodesy, Series II; Translations*, No. 41, Institut für Angewandte Geodesie, Frankfurt A.M.
- BENTKOWSKI, W.H. and T.J. LEWIS. 1983. Preliminary results of shallow drilling in the Garibaldi Volcanic Belt, British Columbia, 1982. *Earth Physics Branch Open File Report 83-23*, 38 pp.
- BORNHOLD, B.D. 1983. Detailed textural analyses of Miocene to Quarternary sediments, Leg 71. *Init. Rep. Deep Sea Drilling Project*, **71**: 1183-84.
- BORNHOLD, B.D. 1983. Sedimentation in Douglas Channel and Kitimat Arm. *Can. Tech. Rep. Hydrogr. Oc. Sci.*, **18**: 88-114.
- BORNHOLD, B.D. 1983. Geological processes in fjords. *Geos.*, **12**: 1-4.
- BORNHOLD, B.D. 1983. Ice-raftered debris in sediments from Leg 71, southwest Atlantic Ocean. *Init. Rep. Deep Sea Drilling Project*, **71**: 307-316.
- CLAGUE, J.J., J.L. LUTERNAUER and R.J. HEBDA. 1983. Sedimentary environments and postglacial history of the Fraser Delta and lower Fraser Valley, British Columbia. *Can. J. Earth Sci.*, **20**: 1314-1326.
- CURRIE, R.G. and B.D. BORNHOLD. 1983. The magnetic susceptibility of shelf sediments, west coast Vancouver Island. *Mar. Geol.*, **51**: 115-127.
- CURRIE, R.G., R. COOPER, R.P. RIDDIHOUGH and D.A. SEEMANN. 1983. Multi-parameter geophysical surveys off the west coast of Canada, 1973-1982. *GSC Paper 83-1A*: 207-217.
- DALY, L. and E. IRVING. 1983. Paléomagnétisme des roches carbonifères du Sahara central; analyse des aimantations juxtaposées; configuration de la Pangée. *Annales Geophysical*, **1**: 207-216.
- DRAGERT, H. 1983. Evaluation of the GDD Electronic Level for relative lake-height measurements. *PGC Internal Report 83-1*.
- DRURY, M.J. and T.G. LEWIS. 1983. Water movements within Lac Dubonnet Batholith as revealed by detailed thermal studies of three closely-spaced boreholes. *Tectonophys.*, **95**: 337-351.
- ELLIS, R.M., G.D. SPENCE, R.M. CLOWES, D.A. WALDRON, I.F. JONES, A.G. GREEN, D.A. FORSYTH, J.A. MAIR, M.J. BERRY, R.F. MEREU, E.R. KANASEWICH, G.L. CUMMING, Z. HAJNAL, R.D. HYNDMAN, G.A. MCMECHAN and B.D. LONCAREVIC. 1983. The Vancouver Island Seismic Project: a CO-CRUST onshore-offshore study of a convergent margin. *Can. J. Earth Sci.*, **20**: 719-741.

- HAMILTON, T.S. and J.L. LUTERNAUER. 1983. Evidence of sea floor instability in the south-central Strait of Georgia, B.C.—a preliminary compilation. In: *Current Research, Part A; GSC Paper 83-1A*: 417-421.
- HERZER, R.H. and B.D. BORNHOLD. 1982. Glaciation and post-glacial history of the continental shelf off southwestern Vancouver Island, British Columbia. *Mar. Geol.*, **48**: 285-319.
- HORNER, R.B. 1983. Seismicity in the St. Elias region of northwestern Canada and southeastern Alaska. *Bull. Seism. Soc. Am.*, **73**: 1117-1137, Contr. 1056.
- HORNER, R.B. 1983. Earthquakes in Saskatchewan: a potential hazard to the potash industry. In: *Potash Technology*, R.M. McKurcher (ed.), *Proceedings of the 1st International Potash Technology Conf., Oct. 3-5, 1983, Saskatoon, Sask.*, 185-190, Contr. 1078.
- HYNDMAN, R.D. and D.H. WEICHERT. 1983. Seismicity and rates of relative motion on the plate boundaries of western North America. *Geophys. Jour. R. Astr. Soc.*, **72**: 59-82.
- IRVING, E. and J.F. SWEENEY. 1982. Origin of the Arctic Basin. *Trans. R. Soc. Can.*, **20**: 407-416.
- JOHNSON, H.P., J.L. KARSTEN, J.R. DELANEY, E.E. DAVIS, R.G. CURRIE and R.L. CHASE. 1983. A detailed study of the Cobb Offset of the Juan de Fuca Ridge: evolution of a propagating rift. *Jour. Geop. Res.*, **88**, 33: 2297-2315.
- LEWIS, T. 1983. Bottom water temperature variations as observed, and as recorded in the bottom sediments, Alice Arm and Douglas Channel, British Columbia. *Can. Tech. Rep. Hydrogr. Oc. Sci.*, **18**: 138-161.
- LUDWIG, W.J., V. KRASHENINNIKON *et al.* 1983. Sites 511, 512, 513, 514. *Init. Rep. Deep Sea Drilling Project*, **71**: 21-109.
- LUTERNAUER, J.L., J.J. CLAGUE and C. PHARO. 1983. Substrates of the Strait of Georgia. *Can. J. Fish. Aquat. Sci.*, **40**: 1026-1032.
- LUTERNAUER, J.L. and W.D.L. FINN. 1983. Stability of the Fraser River Delta Front. *Can. Geotechnical Jour.*, B: 20 pp.
- NELSON, C.S. and B.D. BORNHOLD. 1983. Temperate skeletal carbonate sediments on Scott Shelf, northwestern Vancouver Island, Canada. *Mar. Geol.*, **52**: 241-266.
- PICKRILL, R.A. and R.G. CURRIE. 1983. Computer programs to estimate wave generated orbital velocities and threshold erosion velocities. *GSC Paper 83-1A*: 253-261.
- PRIOR, D.B., B.D. BORNHOLD and J.M. COLEMAN. 1983. Geomorphology of a submarine landslide, Kitimat Arm, British Columbia. *GSC Open File*.
- PRIOR, D.B., J.M. COLEMAN and B.D. BORNHOLD. 1983. Results of a known sea-floor instability event. *GeoMarine Letters*, **2**: 117-122.

- RIDDIHOUGH, R.P., M.E. BECK, R.L. CHASE, E.E. DAVIS, R.D. HYNDMAN, S.H. JOHNSON and G.C. ROGERS. 1983. Geodynamics of the Juan de Fuca Plate. In: *Geodynamics of the Eastern Pacific Region, Caribbean and Scotia Arcs*, R. Cabre (ed.), *Geodynamic Series of the American Geophysical Union*, Washington, D.C., **9**: 5-21.
- ROBERTSON, P.B. and J.F. SWEENEY. 1983. The Haughton impact structure: structural and morphological aspects. *Can. J. Earth. Sci.*, **20**: 1134-1151, Contr. 1041.
- ROGERS, G.C. 1983. Some comments on the seismicity of the northern Puget Sound—southern Vancouver Island region. In: *Earthquake Hazards of the Puget Sound Region, Washington State*, J.C. Yount and R.S. Crosson (eds.), *USGS Open File Report, 1983-19*, Menlo Park, Ca.: 19-39.
- ROGERS, G.C. and J.C. SOUTHER. 1983. Hotspots trace plate movements. *Geos.*, **12**: 10-13.
- SUTHERLAND BROWN, A., C.J. YORATH and H.W. TIPPER. 1983. Geology and tectonic history of the Queen Charlotte Islands. *Geol. Assoc. Canada, Field Guide Book*.
- SWEENEY, J.F. 1983. Evidence for the origin of the Canada Basin margin by rifting in Early Cretaceous time. In: *The Origin of the Arctic Ocean (Canada Basin)*, G.C. Mull and K.M. Reed (eds.), *J. Alaska Geol. Soc.*, **2**: 17-23, Contr. 1040.
- SWEENEY, J.F. 1983. Arctic-Alaska, a two-stage displaced terrane. *Eos, Trans. Am. Geophys. Union*, **64**: 87, 1983.
- WEICHERT, D.H., G.C. ROGERS, R.H. HYNDMAN and R.B. HORNER. 1983. Seismic risk of the Queen Charlotte Islands and adjacent area. *Proc. of the 4th Can. Conf. Earthquake Engin., Vancouver, B.C.*
- WETMILLER, R.J., R.B. HORNER, A.E. STEVENS and G.C. ROGERS. 1983. *Canadian Earthquakes—1980*. Seismological Series of the Earth Physics Branch, Ottawa, No. 87, 60 pp.
- YORATH, C.J. and B.E.B. CAMERON. 1982. Oil off the west coast? *Geos.*, **11**, **2**: 13-15.
- YORATH, C.J. and R.D. HYNDMAN. 1983. Subsidence and thermal history of Queen Charlotte Basin. *Can. J. Earth. Sci.*, **20**: 135-159.

APPENDIX III

Permanent Staff 1983 Institute of Ocean Sciences

A. Department of Fisheries and Oceans Director-General

Mann, C.R.; B.Sc., M.Sc. (N.Z.), Ph.D. (Brit. Col.), D.Eng. (N.S. Tech.), FRSC
Van Dusen, T.S.

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Van Eyk, W.J.	

* Left in 1983

** Joined in 1983

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Trentelmann, E.

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Stone, M.

** Joined in 1983

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Canadian Wildlife Service

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Bunyan, T.C.
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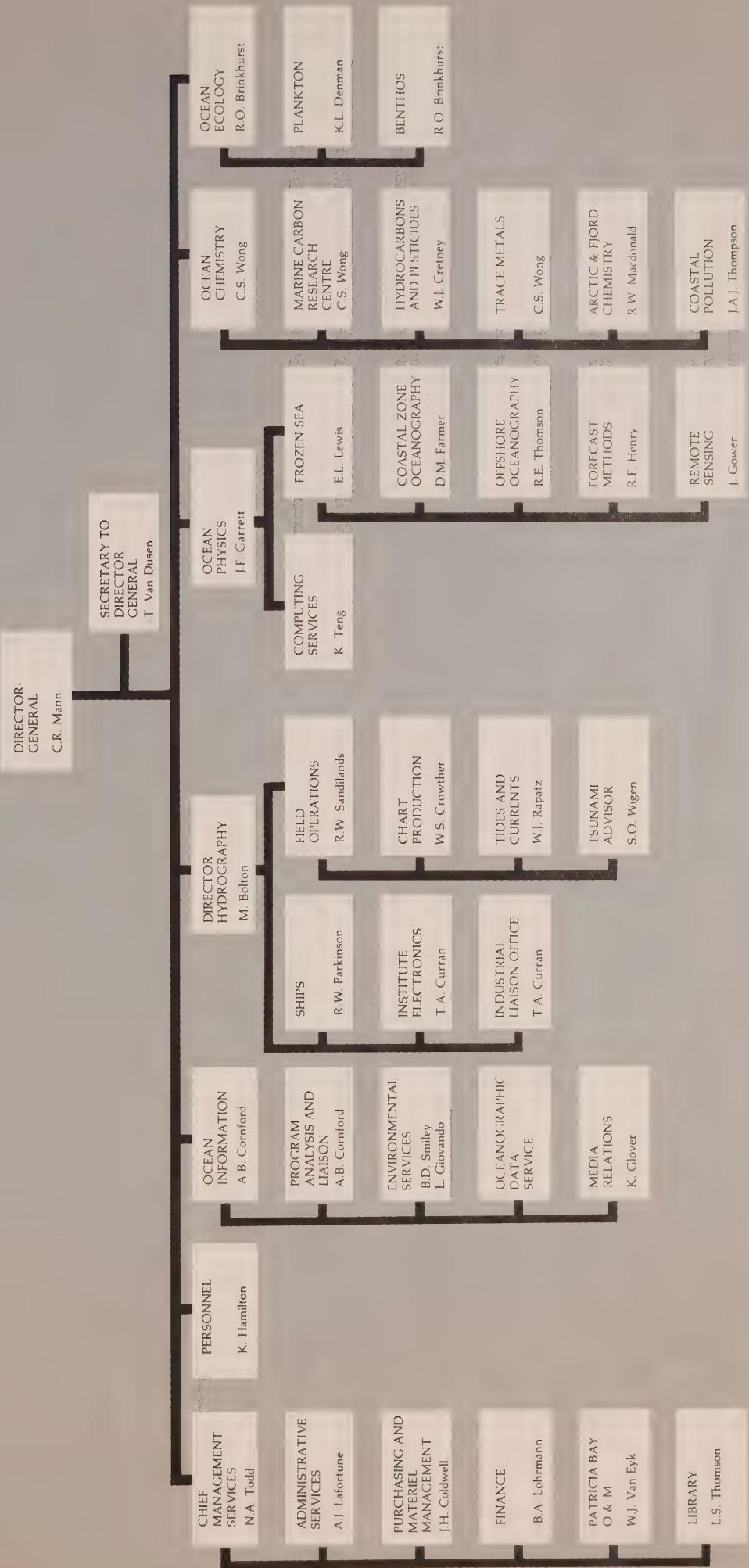
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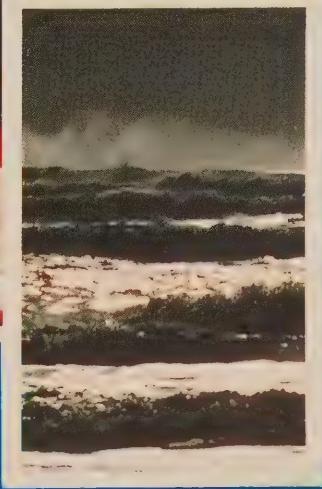
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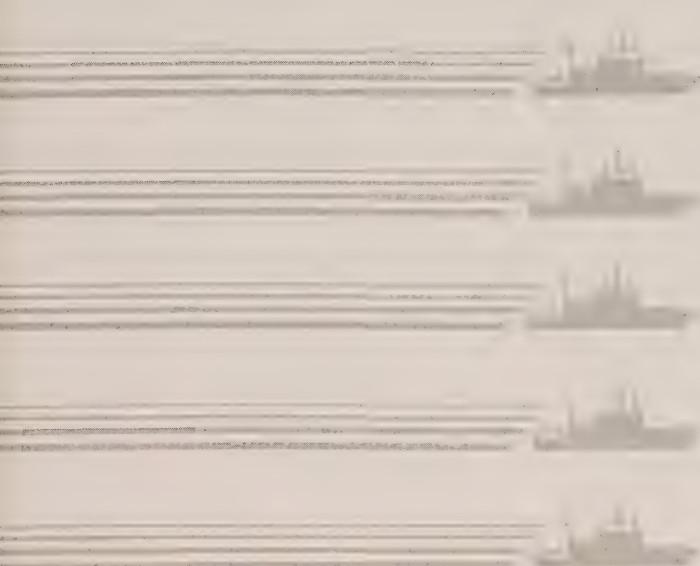
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Department of Fisheries and Oceans



Director General's Foreword

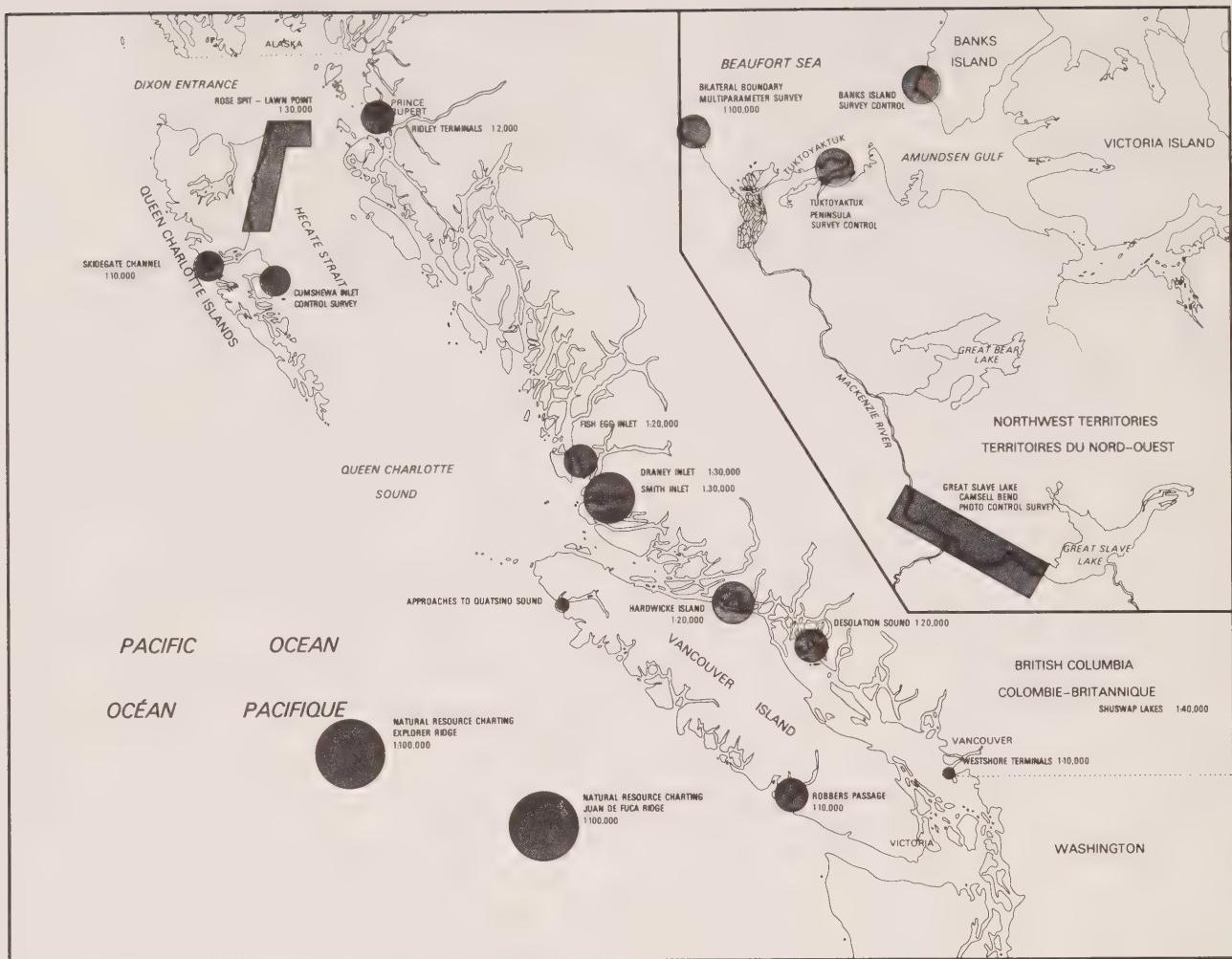


This review is the fourth in the new series of IOS Annual Reviews. We have stayed with a review that sets out our main accomplishments throughout the year in a simple fashion, as we believe such a document should be generally available. Without conducting a survey, the comments we have received have been complimentary and we intend to continue with similar reports in the future.

I do not wish to dwell on any of the programs we have undertaken during the year but do want to comment on a trend that has appeared in physical oceanography. This trend is the increasing number of researchers in other fields who are finding they cannot make progress with the problems they are endeavouring to solve without improved information about the physical characteristics of the ocean. The problem of climate prediction is the outstanding example. The same trend is apparent in attempts to improve the operational forecasting of waves, sea ice, etc. Research in physical oceanography is becoming driven by demand. Fifteen years ago this was not the case, and the majority of research in physical oceanography was exploratory and driven by the desire to improve knowledge of the oceans.

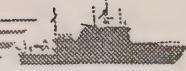
Over the same period of time there has been almost a revolution in the instruments available to the physical oceanographer. The new instruments make it possible to provide vastly improved descriptions of ocean phenomena and have stimulated much theoretical work. Ocean models have now become commonplace, whereas a few years ago they were worked on by only a few interested scientists. They are being constructed on all scale sizes and are being applied to obtain an insight into how the ocean works and to practical problems. I believe this trend is accelerating and that over the next 10 years the funds and the number of physical oceanographers engaged in research will have to be increased if the demands are to be met. Not only will the research have to be increased, it will also be necessary to provide equipment and dedicated people to undertake operational forecasts. Together, these mean a substantial increase in the physical oceanographic community. At the Institute of Ocean Sciences, we will concentrate on climate problems and on forecasting techniques for waves, ice motion, and coastal currents. These are natural directions in which to develop the I.O.S. research program and I hope that we will be able to expand the program in the future.

HYDROGRAPHY



Pacific Region 1984 hydrographic survey program

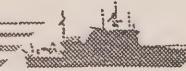
Hydrography



The hydrographic program at IOS includes field hydrography, tidal and current surveys and chart production and distribution. The primary objective of the program is to provide accurate, timely bathymetric and navigational information in the form of nautical charts, tide tables, current atlases and sailing directions. These publications and supplemental information are provided to a variety of clients including mariners, commercial fisherman, sports fisherman, recreational boaters, engineering and consulting firms, other federal government agencies and the general public.

Also covered in this section is Engineering Services, which provides support for hydrographic surveys, oceanographic research and ship operations, in the form of electronic/mechanical engineering and electronics. A major component is an industrial liaison service promoting interaction among IOS, other government departments and the private sector.

Field Hydrography



The Field Hydrography Section is responsible for conducting hydrographic surveys of the British Columbia coast, western Arctic and navigable inland waters in the Pacific Region in order to ensure that the requirements for navigational information are met. Alterations of, and additions to traffic routes, types and sizes of vessels, harbours, bottom topography and coastlines – all require an ongoing and resurvey program.

A major survey party was mounted for a survey of the Shuswap Lake system, a major recreational boating area in the B.C. interior. This survey was completed. (*Contact: B.M. Lusk.*)

An eight-week survey of the northeast coast of the Queen Charlotte Islands from Lawn Point to Rose Spit was carried out by a party operating from

CSS Parizeau. Existing charts of the area are based on surveys of 1911-1918.
(Contact: B.M. Lusk.)



On the Shuswap Lake survey

A second major coastal survey party completed a survey of the Hardwicke Island region and then moved to the uncharted Fish Egg Inlet area. At the end of the season the uncharted head of Boswell Inlet, Wyclees Lagoon and Draney Inlet were surveyed and Smith and Naysash Inlets were resurveyed to modern standards. (Contact: A.R. Mortimer.)

A small party onboard *CSS Richardson* completed large scale surveys of Uganda Passage and Roscoe Bay for a projected chart atlas of the Desolation Sound area. (Contact: G.H. Eaton.)

In the Queen Charlotte Islands, a *CSS Richardson* party continued surveys of Skidegate Channel, completing Trounce Inlet, the west narrows and Armentieres Channel. A continuing survey of Quatsino Sound was completed. (Contact: J.V. Crowley.)

Shore based parties carried out the following small projects: a survey of Robbers Passage, Barkley Sound (Contact: J.V. Crowley); completion of the survey of Ridley Island Terminal where construction equipment had precluded completion in 1983 (Contact: J.V. Crowley); and a large scale survey of Westshore Terminal at Roberts Bank where a new loading terminal had been constructed and dredging had taken place in the turning basin. (Contact: G.E. Richardson.)

In the western Arctic, survey control was strengthened in the Herschel Island to Banks Island area. A multi-disciplinary survey under contract to Cansite Surveys Ltd. of Calgary was carried out between the Alaska/Yukon boundary and Herschel Island and after a slow start due to poor ice conditions the bathymetric portion was completed during a late ice opening in September. (*Contact: G.H. Eaton.*)

Surveys for sailing directions and chart revisions were carried out under contract to Coast Pilot Ltd., Sidney. A revisory inspection for the Pitt River chart was completed by staff. (*Contact: G.E. Richardson.*)

Sailing Directions

The Thirteenth Edition of *British Columbia Coast Sailing Directions (South Portion)*, Volume I was published in December. This edition contains new information on tidal streams, vessel traffic services and port facilities. New photography and several new diagrams were incorporated into this edition. Volume I and Volume II (North Portion) are published in alternate years. (*Contact: Volume 1, A. Smith; Volume II, J.W. Roberts.*)

Small Craft Guide, Volume II (Boundary Bay to Cortes Island) Fifth Edition was published in May. (*Contact: L.M. Chan.*)

Field inspections for revisions were carried out on the Mackenzie River and the B.C. coast.

Hydrographic Development

Hydrographic data processing software was enhanced this year by an improved multi-range positioning solution and an improved data cleaning package. Hydrographic Acquisition and Logging (HAL) data loggers and processing software were fully tested prior to the field survey on CSS *Parizeau*. HAL loggers have completely replaced the older PHAS (Portable Hydrographic Acquisition System) units for hydrographic data collection in the region.

Two Unsolicited Proposal contracts were completed this year. A hydrographic contouring package was delivered in June and full testing was applied on the *Parizeau* data during post-cruise analysis. Test conclusions are not yet available.

Also in June, hardware and software were received to digitize and plot shoreline and control from aerial photographs. The equipment is compact

and portable enough to be ship or field office based, and was used on the Shuswap Lake survey.

As a result of a contract, Liquid Crystal Display (LCD) remote readouts were developed and supplied for Trisponder 540, mini-ranger and mini-ponder type positioning systems. They greatly enhance visibility in high ambient light conditions and enable greater flexibility in instrument package siting in smaller boats. Several field parties used the remote readout units. (*Contact: J.B. Larkin.*)

Chart Production and Distribution



The functions of the Chart Production and Distribution Section are to ensure that survey and other data are processed for publication as expeditiously as possible and to ensure that a ready supply is available for all users.

Ten new standard charts were produced in Pacific Region this year in addition to 64 new editions and 14 reprints. A heavy load of hand amendments (1.3 million on 160,000 charts) precipitated the preparation of 14 overprintings and 11 chart amendment patches were required. The Chart Sales office distributed 161,534 charts, 77,314 publications and 32,136 information brochures during the year.

Fifteen Notices to Shipping and 155 Notices to Mariners were issued, necessitating 191 chart amendment tracings, and 1304 MAREP (the Canadian Power Squadron's Marine Reporting Program) reports were processed.

Four staff attended CARTO I and three senior staff attended the CARTO II training program.

One year has now passed since the VAX 11/750 came on line. All the software required to process a digital chart file is now in place. Disk-to-disk processing and the faster operating speed of the VAX has resulted in a decrease of approximately 30% in file handling and processing time. With digitizing, editing (GOMADS) and file processing all able to operate

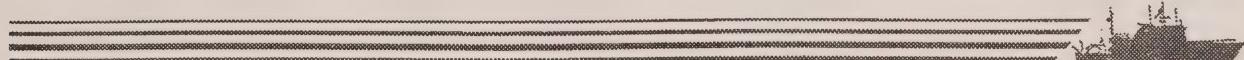
simultaneously the VAX has more than doubled digital chart production capacity.

Promotional and educational activities continued with participation in two boat shows. Other activities included tours and lectures for Canadian Power Squadrons and university students.

A DEC Rainbow 100 computer was purchased for the Chart Sales and Distribution office, replacing a Radio Shack TRS 80 computer. Acquired primarily for accounts receivable and inventory control, it is also proving to be an effective tool for the planning and scheduling of the chart amendment program.

The cancellation of Chart 3450, East Point to Sand Heads, in September marked the end of an era in the history of charting west coast Canadian waters. First published in 1937, it became one of the best selling charts in Canada and a standard aid used in navigation courses, including those operated by the Department of Defence, Canadian Power Squadron and numerous sailing schools.

Tidal and Current Surveys

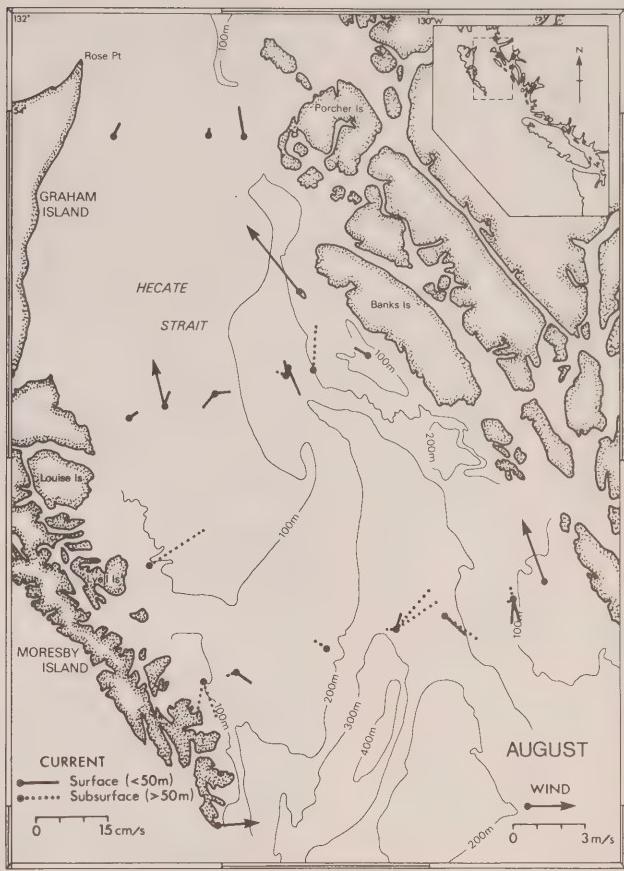
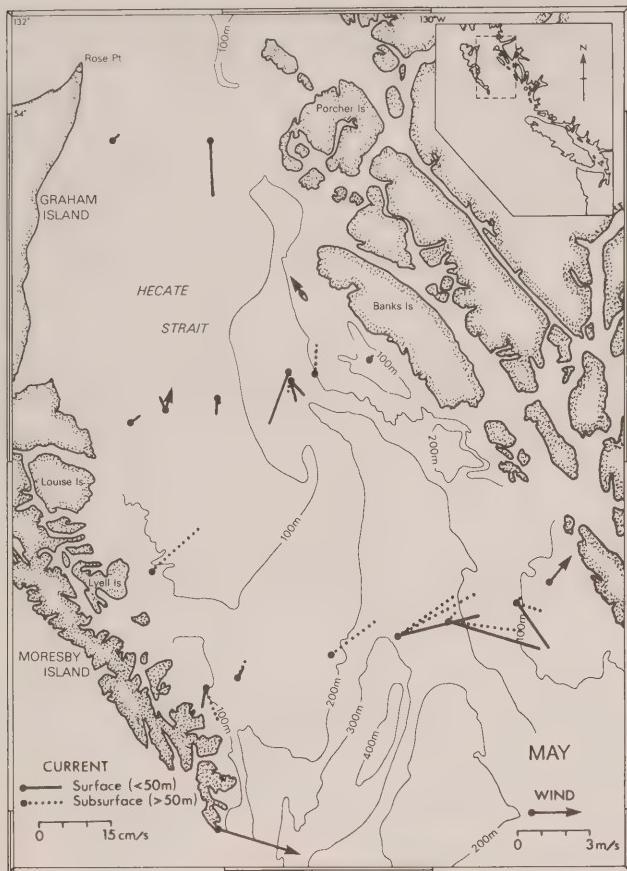


A study of the circulation in the waters surrounding the Queen Charlotte Islands, which began in 1982 in Queen Charlotte Sound, was extended into Hecate Strait, to the west coast of the Queen Charlottes (in collaboration with Ocean Physics Division), and further into Dixon Entrance. Cruises were mounted in January, April and in October. Losses of some current meter moorings were sustained due to fish boat interference near the Alaska coast. To provide data for numerical modelling of the area, 10 near-shore bottom pressure gauges were deployed, including three near the Alaska coast. Much of the instrument data processing was done at sea allowing some preliminary analysis to be carried out before the moorings were redeployed. (*Contact: W.S. Huggett.*)

Complementary to the moored instrument survey, a surface drifter study was carried out under contract for a period of two weeks in July. This was the first full field trial for the Loran-C telemetering drifters and, despite a few problems, enough data was collected to show the main features of the surface currents. (*Contact: W.R. Crawford.*)



The current meter data gathered during the 1982 and 1983 field seasons in Queen Charlotte Sound and Hecate Strait reveal a circulation pattern dominated by the winds. In Queen Charlotte Sound in summer, winds from the northwest tend to push the fresh water out of the Sound over Cook Bank, past Cape Scott and into the Pacific Ocean. During southeast winds, the fresh water is confined to the eastern side of Hecate Strait and Queen Charlotte Sound, flowing to the northwest. The 12 months of current meter data from Hecate Strait reveal that in winter, when the prevailing winds blow strongly from the southeast, most of the river runoff is swept into Dixon Entrance, although a portion of this water appears to flow southward along the eastern side of the trench running along the Strait. Average currents observed in four separate months are illustrated. The pattern of currents described above shows clearly in November and February. In May and August the strong southeast winds abate, to be replaced by calmer weather with prevailing winds from the northwest. Consequently, currents are weaker and tend to flow to the southwest along



the sides of the Strait, with a return flow in the centre of the channel. Models of this circulation are being developed in an attempt to predict the northward transport of fresh water under different wind and runoff conditions. (*Contact: W.R. Crawford.*)

A current survey in Nakwakto Rapids and at several sites in the Seymour Inlet complex was completed in order to improve predictions in these fast-flowing narrows. The method used in Nakwakto Rapids involved the measurement of along-channel pressure gradient over a period of one year in order to extend the short series of current observations. Software development to determine the necessary empirical models, to form the extended time series and to compare the results with existing predictions and historical data is nearing completion.

Comparison of 10 different types of current meter, the field work for which concluded in September of last year, was substantially completed. This study shows that noise to signal ratios of 10 are not uncommon for current

meters suspended close below a surface float. There is considerable variation in the performance of different instruments under these conditions. (*Contact: M.J. Woodward.*)

Continuing previous practice, tidal records from 21 permanent, five temporary and several hydrographic stations were processed and the data forwarded to Marine Environmental Data Centre for archiving. Data from three Pacific coast tide stations are being forwarded each month to IGOSS as Canada's contribution to a Pacific mean sea level anomaly study.

A study of mean sea levels on the west and east coasts of central Vancouver Island was continued. This work is being done at the request of the Pacific Geoscience Centre as part of a program to measure and study earthquake induced crustal movements.

Work continued on hardware and software for two Meteor Burst tide stations. After testing and evaluation this unit will be installed at Queen Charlotte City. (*Contact: F.E. Stephenson.*)

The measurement of tides and long-term mean sea level variations in the Queen Elizabeth Islands continued. The three stations on the Arctic coast of the archipelago were serviced in May and Pond Inlet was visited in August. Two bottom-mounted pressure recorders are now installed at each of the four sites. This study is being supported in part through funding from HARP (High Arctic Research Program).

The bottom-mounted pressure recorders at the five permanent stations in the western Arctic were serviced and redeployed in July and August. Analog bubbler gauge stations are also being maintained at Tuktoyaktuk and Cambridge Bay.

A pressure recorder installed at Baychimo in 1983 to determine mean sea level at that location for Geodetic Survey of Canada was serviced and redeployed for one more year. (*Contact: F.E. Stephenson.*)

Campbell River Estuary

At the request of the Pacific Biological Station, a year long study of the Campbell River Estuary started in July 1984. The study involves measurements of tides, currents, salinities and temperatures throughout the four seasons and at a variety of tides and river discharge states. The study is

being carried out in close cooperation with fisheries scientists. The objective is to discover how an environmental enhancement project carried out by B.C. Forest Products Ltd. might affect salmonid feeding grounds. The project will include a numerical tidal model including, if possible, the salinity intrusion.

Fraser River Estuary

Participation in the development of a Federal-Provincial program of long-term environmental monitoring for the Fraser River estuary continued until the fall of 1984 when a final report, "Fraser River Estuary Monitoring — A Recommended Approach", was submitted to Environment Canada and to the Department of Environment, Province of British Columbia.

Production runs of the Fraser River numerical model continued throughout the year to assist such interests as shipping on the lower reaches of the river, construction projects and various court cases.

Current, salinity and temperature measurements continued in the trifurcation area and in the reaches leading to Canoe Pass. Detailed time series were conducted in the vicinity of the construction site of the new bridge crossing the Fraser at Annacis Island.

Skeena River Estuary

A helicopter survey of salinities, temperatures and currents in the lower part of the Skeena River was conducted in the early spring. This survey suggested the development of a portable instrument which could measure and record a variety of estuary features from a helicopter or hovercraft.
(Contact: A.B. Ages.)

Diving Unit

By far the most common diving activity in 1984 was the placement and/or recovery of bottom mounted pressure gauges at various sites on the Pacific coast and in the western Arctic. In excess of 20 locations were visited during the year. This work was done for programs being conducted by Ocean Physics Division and Tidal and Current Surveys.

Divers also carried out several propeller inspections for the *Parizeau* and assisted in the recovery of weather buoy moorings in Dixon Entrance and at the entrance to Juan de Fuca Strait.

Closer to home, divers assisted the Ocean Physics group in the design of a bracket to attach two transducers to the keel of the *Vector*. This unit was used to measure lateral movement in struts supporting an echometer system. (*Contact: F. Stephenson.*)



Surfacing after tide gauge deployment at Coppermine, N.W.T.

Engineering Services



Engineering Services provides electronics and mechanical engineering and electronics support for hydrographic surveys, oceanographic research and ship operations and an industrial liaison service promoting interaction between IOS, other government departments, and the private sector. (*Contact: T.A. Curran.*)

Engineering Development

This group provides custom development of hydrographic and oceanographic instrument systems, management of government-funded contracts and consultations to all IOS groups.

Instrumentation projects completed in 1984 included a portable current meter, a Meteorburst tidal telemetry system and development of a sensor for measurement of zooplankton populations. A pressure test facility, capable of operation to an equivalent depth of 6000 metres, was brought into full operation.

The Active Drifter hardware underwent additional testing with successful trials of the station-keeping navigation sub-system and implementation of power management hardware. Local contracts involving the Active Drifter included development of an efficient and reliable thruster and a detailed engineering study of UHF antennas. The Active Drifter concept was presented to the engineering community at PACON 84.

An increasing level of effort is being directed to the application of acoustics with the construction of a number of standard electronic modules for hydrographic and oceanographic applications. Mechanical components for an *in situ* acoustic calibration facility were constructed and installed at IOS and this facility was used to calibrate and test components of the acoustic video telemetry system. A study was undertaken to identify methods by which the depth capability of launch sounders could be extended. Modifications were made to the IOS-developed Sterntow sounder electronics to facilitate use of different transducers in the Atlantic.

Significant engineering support was provided for the *Pisces IV* program with the purchase and installation of an ultra-short baseline acoustic navigation system and subsequent novel modifications to the support vessel's ram which gave additional maneuvering freedom. A suite of scientific tools developed under contract were installed on the submersible.

The group's contract management responsibilities include supervision both of complete instrumentation development contracts and of smaller contracts which augment "in house" developments. The year saw completion of the shipboard version of the correlation sonar current meter development contract. Contracts for development of unique solar panels and an equally unique acoustic release mechanism were nearly completed and encouraging results were achieved with the laser diode pressure sensor

contract. An evaluation was completed of the SeaMARC II swath survey acoustic system which was tested off Vancouver Island. (Contact: J. Galloway.)

Institute Electronics

Calibration, repair, installation and routine maintenance of equipment in support of hydrographic and oceanographic programs and ship operations were successfully performed during the year. The major equipment areas were radios, depth sounders and digitizers, positioning systems and data loggers.

In the communications area, approximately 65 VHF-FM and 15 HF/SSB transceivers were maintained. A radio teletype system (TOR) was installed at IOS and interfaced to the HF radio station for direct hard copy text communication with *Parizeau*. Two Glenayre HF data message terminals were obtained for evaluation purposes, one at IOS and the other on *Parizeau*. Results to date are very encouraging and steps are being taken to gradually fit IOS vessels with terminals.

The sonar group maintained 28 survey type and navigational depth sounders as well as numerous small digital sounders and 12 sounder digitizers. In addition two velocimeters were serviced and maintained.

Approximately 21 microwave positioning units, 15 Argo units, two transit satellite navigation systems and several Loran-C and Omega systems were serviced.

All fine data logging systems received a thorough overhaul which included hardware and software changes.

Ships, launches and the barge *Pender* were fitted out for hydrographic purposes.

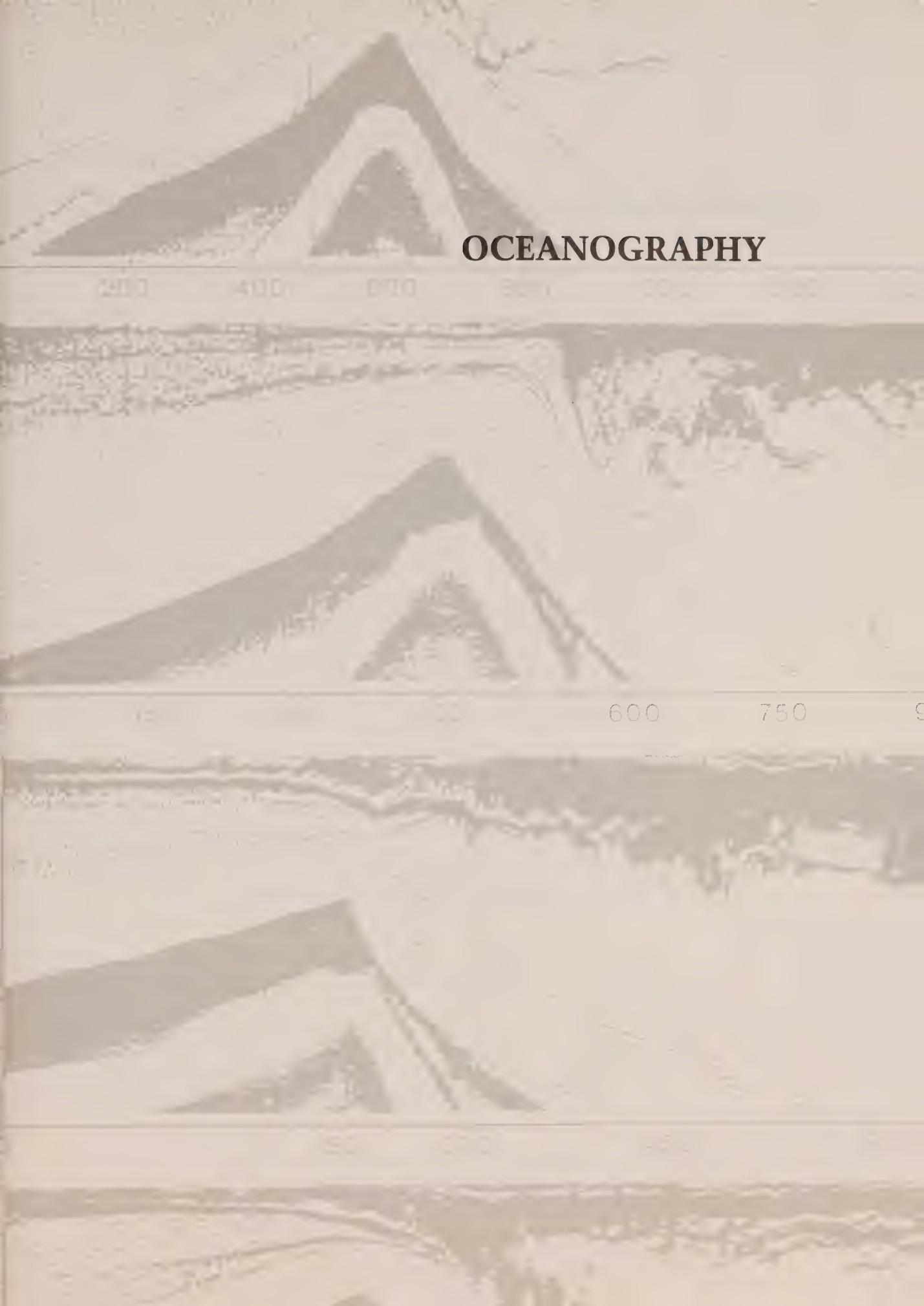
Field suport was provided for hydrographic survey on *Parizeau* and local support was provided to local survey parties.

Continuing support was provided to Computing Services in the maintenance of the Kongsberg drafting system. (Contact: W. Ron Taylor.)

Industrial Liaison and Contracting

The Institute of Ocean Sciences has an established policy of conducting a significant portion of its program through contracts to the private sector.

In addition to contracting out directly, IOS participates in such government ventures as the Unsolicited Proposals (UP) program with the Department of Supply and Services (DSS), and both the Program for Industry/Laboratory Projects (PILP) and the Industrial Research Assistance Program (IRAP) with the National Research Council (NRC). IOS was involved to some extent in 116 contracts in the past year, ranging in value from less than one thousand dollars to approximately one million dollars, and with a total value in excess of \$4.8 million. (*Contact: T.A. Curran.*)



OCEANOGRAPHY

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Ocean Physics



Circulation and Climate

During 1984, three ocean climate monitoring cruises were made. This brings to 11 the number of cruises along Line P, the northern Line R, and other associated lines since the withdrawal of the weatherships from Ocean Station Papa. (*Contact: S. Tabata.*)

The characteristics of both the annual and interannual variability of steric height (the change in sea level due to the fact that a given mass of colder or saltier water takes up less volume than an equal mass of warm fresh water) off the Pacific coast of Canada, based on Line P data, can be grouped under three main categories according to their locations: open ocean (beyond continental slope), transitional region (continental slope) and coastal region (continental shelf to shelf edge). In the open ocean the temperature effect dominates the annual change of steric height whereas along the coastal region the salinity effect dominates. There is little evidence that the large-scale offshore circulation of the Subarctic gyre is relevant to the annual cycle of mean sea level along the coast. Precipitation and runoff, wind-induced transports and coastal currents appear to be important to the annual variation of coastal steric height. (*Contact: S. Tabata.*)

One of the obstacles to development of reliable large scale models of ocean circulation is the lack of understanding of exactly how eddies affect the exchanges of momentum, heat and salt. Eddies are known to be common in many parts of the ocean, and cannot be ignored. In view of the complex nature of the flow fields involved, theoretical studies often focus on statistical descriptions, analogous to those used in work on small scale turbulence. One way of evaluating the effects of an eddy field is to examine the changing distribution of particles in the field.

Numerical simulations of idealized oceanic (or atmospheric) eddy fields have been developed. They include large-scale mean gradients of a passive tracer (dye) and large-scale mean gradients of ocean current. The movements of particles (floats) can also be followed. Results show that the efficiencies of tracer transport and of particle dispersion are reduced with increased stratification or with increased change of rotation with distance. This suggests that eddy exchanges over the continental slope should be

inhibited. (*Contact: G. Holloway.*)

These models were applied to examine the relative importance of eddy stirring, spatial variations in the growth/decay rate, and lateral diffusion in maintaining spatial patchiness in phytoplankton biomass. As might be expected, the results depend on the time scales of growth/decay relative to those of eddy stirring; only when they were similar did the eddies have much effect on the spatial structure of patchiness. (*Contact: G. Holloway.*)

In a related study, numerical experiments were used to explore the factors controlling the stirring of plankton across a frontal zone paralleling the shore, in three types of current fields emulating those thought to exist over the continental slope. The most striking result shows that shelf waves tend to suppress the cross-frontal exchanges relative to either eddies which are locked to topographic features or eddies which self-direct along the coast. In all cases there is a rich, time dependent sequence of plankton patterns not unlike those observed in satellite images. The output from the model was used to generate a 16 mm colour film. (*Contact: G. Holloway.*)

Theoretical studies of dispersion processes stimulated an analysis of TWERLE high altitude balloon pair data (provided by the U.S. National Center for Atmospheric Research) and matching high altitude wind fields (provided by the Australian Bureau of Meteorology). These demonstrated that relative dispersion in large scale quasi-geostrophic turbulence, such as found in the atmosphere and ocean, is a non-local process. The shear in the most energetic eddies controls the relative dispersion on all smaller scales, so that particle separations grow faster than would otherwise be expected. (*Contact: A. Bennett.*)

Continental Shelf

The data collected off Vancouver Island during the Coastal Ocean Dynamics Experiment (CODE) between 1978 and 1983 continue to yield valuable results. Diurnal currents along the west coast of Vancouver Island were found to have the spatial structure expected of baroclinic continental shelf waves rather than the usual Kelvin wave. Continental shelf waves thus turn out to be important to investigation – a far cry from the theoretical curiosities they were originally thought to be! Off Brooks Peninsula the current gradients are large enough to lead to the formation of “eddies” 50 km in diameter, in which large pools of anomalously fresh water become detached from the northward flowing coastal current to

drift slowly southward along the edge of the continental shelf. The results of several recent experiments were combined to produce a general summary of seasonal currents off the southern B.C. coast.

The focus of efforts aimed at obtaining a preliminary description of currents on the west coast has now moved northward. An array of current meter moorings is being maintained west of the Queen Charlotte Islands and in Dixon Entrance until at least May 1985. (*Contact: R.E. Thomson.*)

The complex bottom topography typical of the B.C. coast has made it difficult to test theories regarding the low frequency continental shelf waves which might be one of the mechanisms by which disturbance generated by distant events, such as El Nino, can propagate to local waters. The continental shelf off East Australia is remarkably regular and smooth, which led IOS scientists to propose an experiment there to test the theories. The idea received an enthusiastic response in Australia and the U.S. with the result that an international current meter mooring array was installed for six months ending in March 1984. The IOS team had the best instrument (100%) and data (90%) recovery rate among the groups participating. Preliminary results show that continental shelf waves were observed, but that they propagate more slowly than expected. (*Contact: H. Freeland.*)

Ocean current and sea level observations from the Beaufort Sea Project of 1974-75 were examined for the presence of shelf waves. Existing theory on shelf waves was applied to the shelf geometry of this area to facilitate their identification in available data. Measurements of current at the shelf edge in the Beaufort Sea during 1981, which revealed strong semi-diurnal oscillations, were studied in light of existing theory on internal tides. Studies of 1981 observations revealing a shelf break undercurrent, and a freezing-driven thermohaline circulation continued. Modelling work on wind-driven barotropic circulation over the shelf was initiated using the shallow-water-equations model of Henry and Heaps, and simplified analytical representations of shelf circulations due to Csanady are being explored. (*Contact: H. Melling, P. Budgell.*)

The N.W. Passage oceanographic program continued with the collection of data in the region of Barrow Strait. These data were relevant to the description and understanding of tides, water structure and current velocity including year-long current information. Completion of the survey in 1984 entailed measuring 144 CTD profiles for the purpose of identifying water masses and baroclinic circulation. The CTD stations were concentrated in the waterways adjacent to Cornwallis Island,

although selected stations over a wider area in the Archipelago were revisited again. Two tide gauges and twenty current meters were deployed from the ice for a three-month period at 2 cross-sections in Wellington Channel and in Barrow Strait. Data from this survey, together with those from earlier years, have been processed and documented. (*Contact: H. Melling.*)

Long-term current, temperature and salinity measurements were continued in 1984 with the objective of documenting seasonal variability in the Arctic. A mooring deployed in April 1983 in Austin Channel was recovered in April 1984, with successful 12-month data records obtained from a seafloor pressure gauge and from 2 current meters. Efforts to recover 2 similar moorings in Barrow Strait, deployed by the Bayfield Laboratory in April 1983 were unsuccessful as the moorings could not be located despite attempts both in April and in September 1984. The moorings are presumed lost. Two additional moorings were deployed at nearby locations in Barrow Strait in April 1984. A further two moorings were deployed in Penny Strait in April 1984.

In an effort to understand the reasons for inflow of water into the Archipelago from the Arctic Ocean, moorings were deployed in April on its western periphery (2 in M'Clure Strait and 3 in Ballantyne Strait) in conjunction with sea-level measurements at Auldhild Bay, Isachsen and Mould Bay by CHS. Temperature and salinity measurements were also acquired on a section running northwest off the shelf into deep water. Tide gauge recoveries are scheduled for late May 1985. (*Contact: E.L. Lewis.*)

Upper Layer Processes

Field work for project SUPER (Subarctic Pacific Ecosystem Research) was carried out during May in conjunction with IOS Ocean Ecology and University of Washington scientists. The objective of this experiment was to determine why the Northeast Pacific is unique in having no spring plankton bloom. The physical oceanographers involved were responsible for obtaining measurements of the physical processes affecting the plankton during the experiment, which took place near Ocean Weather Station P (50°N, 145°W). A drifting instrument array was operated all through the experiment to provide meteorological data and a time history of water temperatures down to 200 metres depth. The FLY turbulence profiler was used to measure levels of turbulence, which can result in plankton being mixed down out of the zone of high light intensity. (*Contact: A. Gargett.*)

Observations over the last few years of near-surface waters under ice in the Arctic have frequently revealed a temperature depressed by as much as 0.01°C below freezing temperature. The existence of such supercooling is puzzling in the light of current understanding of the freezing of sea water. Moreover, it represents some capacity to grow ice should the supercooling be relieved. These observations stimulated the initiation of a laboratory experiment to grow ice in seawater under carefully controlled conditions of temperature and temperature gradient, and to observe the growth through still photography. Analysis of results is not yet complete.
(Contact: E.L. Lewis.)

Forecasting Methods

Trials of the 2 km mesh computer models of the Georgia-Juan de Fuca Strait system confirmed earlier experience of the remarkable sensitivity of the modelled tides to adjustments of frictional dissipation. It became necessary to modify the computational scheme to include fractional mesh widths at a number of locations where flow restrictions occur. A successful calibration was achieved for the combined non-linearly interactive M_2 and K_1 tides. Using data sequences from the above trials as input, successful tests were made of an extended version of the buoyant spreading upper layer model used to include the effects of the Fraser River plume.
(Contact: P. Crean.)

The original, overall tidal model was modified to incorporate prepared wind fields and observed sea levels on the southern open boundary for simulation of the December 1982 storm surge. For comparison purposes, a simulation of tides for that period was completed. A test simulation of the surge encountered some inconsistencies between U.S. and Canadian sea level datums to which gauge elevations are referred. *(Contact: T. Murty.)*

A linear superposition method was developed using independent component solutions for objective interpolation between observed tidal elevations inshore of the Queen Charlotte Islands. Satisfactory fits to the observed principal diurnal and semi-diurnal constituents were obtained and cotidal charts are being prepared. An irregular triangular grid model was also developed to permit better resolution than is possible with the finite-difference model. Preliminary work on the tidal currents was carried out during the study of tidal elevations. It was evident that spurious topographic waves generated during the spin-up to steady oscillation

conditions can mask the genuine tidal current field, a phenomenon not previously reported in the literature. (*Contact: R.F. Henry.*)

Several stages in the development of a finite-difference barotropic model of the Northwest Passage were completed. An irregular, triangular grid was developed which fits the coastline well and maintains an approximately constant area/depth ratio over all grid elements. Corresponding water depth data were assembled and certain modifications to Thacker's finite-difference scheme required for this application were completed. Initial simulations of the M_3 tidal constituent indicate that the model is stable and calibration against tidal observations is proceeding. A graphics program was written to permit display of quantities computed on the irregular grid. (*Contact: T.S. Murty.*)

New requests from various countries for the tidal analysis package have brought the total distribution to 69 institutions worldwide. Numerous enquiries relating to the use of these programs were answered and the manuals were reprinted. (*Contact: M. Foreman.*)

In response to a request from Environment Canada, an existing numerical storm surge model of the southern Beaufort Sea was adapted for detailed study of extreme water levels at Tuktoyaktuk and surroundings. Extreme winds over the shelf, computed by Atmospheric Dynamics Corporation, were used to predict 100-year surge levels at Tuktoyaktuk. Seaconsult Marine Research computed maximum wave heights for the same extreme winds. The results of the surge and wave predictions were combined to produce a 100-year flood risk map which indicates that most of the village and airstrip would be submerged. However, confidence in this result is limited due to the inadequacy of historical water level observations. (*Contact: R.F. Henry.*)

Advisory and planning work on future programs on storm surges in the Bay of Bengal continued in response to specific requests from the World Meteorological Organization. A numerical model of the Arabian Sea was developed and used to simulate diurnal and semi-diurnal tides in order to plan observation programs. A review paper on the storm surge problem in the Bay of Bengal reached final draft stage. (*Contact: T.S. Murty, R.F. Henry.*)

Observing Methods

Following the development of a general theory of the response characteristics of conductivity cells and its successful application to the Neil Brown

range of cells, an experimental test program was designed for the Guildline Mk IV CTD temperature and conductivity sensors, to elucidate the response characteristics of the sensors over a speed range 0.25 to 1.8 m/sec of fall speed. A preliminary analysis of the results indicates a close agreement between the measured response of the conductivity cell and the predictions of the theory. The temperature sensor response exhibited a significant sensitivity to lowered speed, and a simplified analysis suggests that a significant component of this speed dependence arises from the spatially distributed nature of the sensor design. The remaining speed dependence is thought to be a Reynolds number scaling effect on the heat transfer characteristics of the sensor.

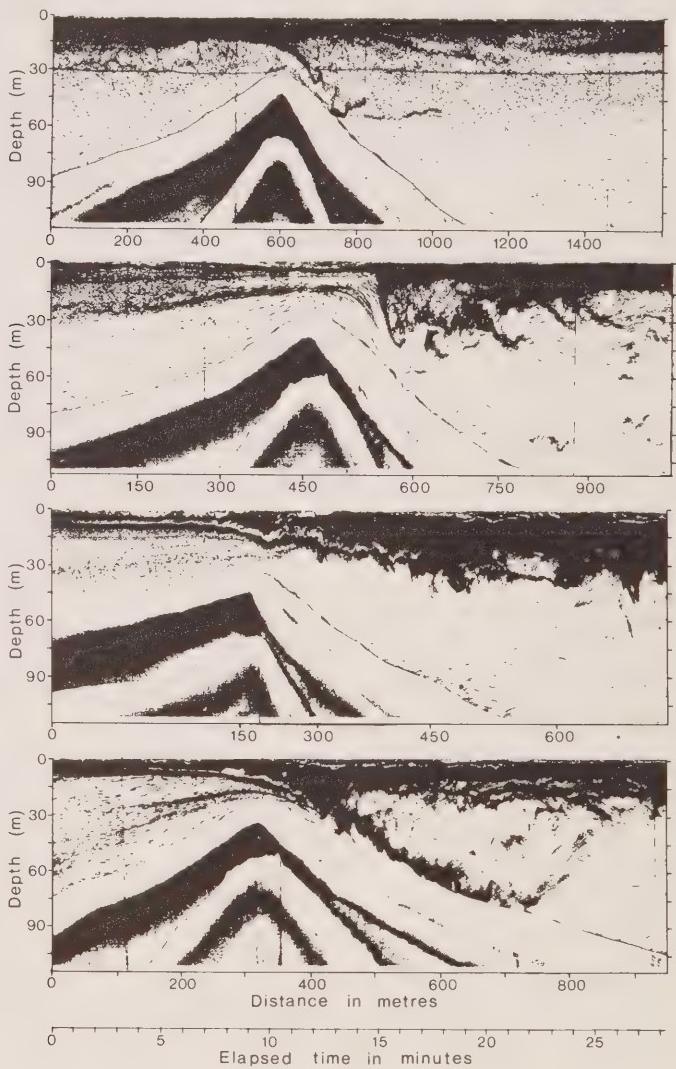
The analysis also suggests that by increasing the length of the temperature sensor, its speed dependence can be more closely matched to that of the conductivity sensor. With the existing designs, a good match between the conductivity and temperature sensors is only achieved at a single lowering speed of about 1.5 m/s. Increasing the length of the temperature sensor would extend the matching condition over a range of lowering speed; an important consideration where ship motion modulates the lowering speed.
(Contact: D. Topham.)

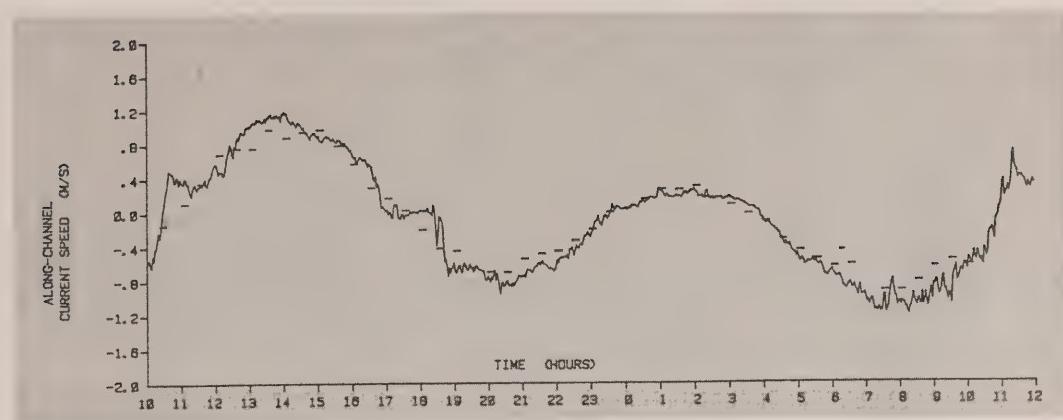
The investigation of acoustic techniques for measurement of physical oceanographic processes continued at IOS in several ways, including the activities of a graduate studies group through the University of Victoria (plus one student at the University of British Columbia). Studies focussed on three areas of acoustic remote sensing: ambient noise in the ocean and its interpretation in terms of air-sea interaction processes, the use of back-scatter sonar systems to measure various water properties and propagation experiments to determine features of the flow field through its effect on sound travelling through it.

The program of measurement and interpretation of underwater ambient noise has revealed new insights on the mechanisms of generation and absorption of high frequency sound in the ocean. Individual wave-breaking events have been identified and the slower modulation of sound by moving clouds of bubbles has been observed. Theoretical modelling of these processes is aimed at deepening understanding of the processes at and near the air-sea interface which account for the highly variable nature of observed signals. The program has now been extended to the observation of sound caused by precipitation. Rainfall, hail and even snow have distinguishable acoustic spectra which have been identified in a pilot study in Cowichan Lake.

Completed projects included a study of acoustic Doppler techniques and their application to study of internal hydraulic flows over a sill and a back-scatter sonar project involving the study of bubble distributions beneath breaking waves, obtained from the submarine U.S.S. *Dolphin*. The IOS Doppler sonar was also used to study vertical motions in tidal fronts. The simultaneous use of an echo-sounder, Doppler sonar and microstructure shear probe is aimed at resolving the structure of these energetic processes over a range of scales (from dissipation scales up to several tens of metres). Also, a program of observation and theoretical analysis is being carried out to determine the phase structure of sound scattered by biological targets; the results having application to the remote measurement of temperature in the ocean.

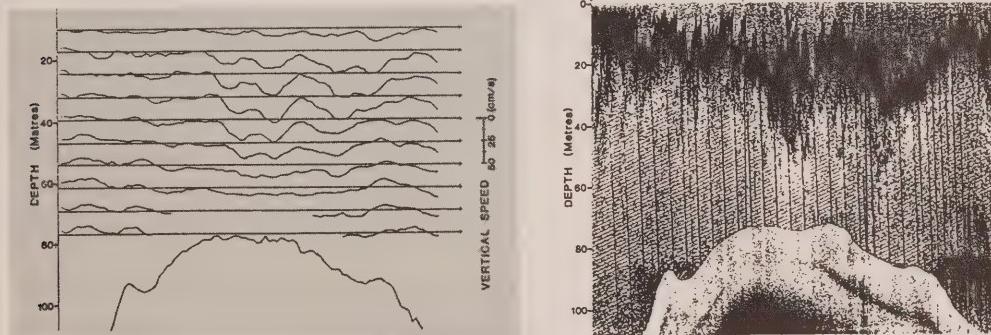
Echo-sounder images of flow over the Observatory Inlet sill at various stages of the ebb tide. The evolution of the internal response (which was also tracked with a Doppler sonar and a towed CTD) is analyzed as a three-layer internal hydraulic flow. In the second image, a transition is occurring between two types of internal response (mode two and mode one) and the hydraulic control has advanced upstream from its usual location at the sill crest. This leads to the peculiar condition of a symmetric, super-critical flow over the crest, which suddenly breaks down and forms a rotor about 80m downstream of the shallowest point.





Comparison of current speeds in Cordova Channel derived from a moored recording current meter (continuous line) and from an acoustic scintillation system (horizontal bars). The scintillation measurements were obtained by transmitting an acoustic signal across the channel and receiving at two horizontally separated hydrophones. Turbulent fluctuations in the water mass move with the mean flow; the corresponding motion of the acoustic pattern through the hydrophone array is then used to deduce the current speed.

In August, an experiment was carried out in Cordova Channel to test the application of acoustic scintillation measurement in the ocean. The acoustic system, consisting of a projector on one side of the channel and two hydrophones on the other, operated successfully over a 600m path. The device exploits the concept of an acoustic shadowgraph, the translation of the resulting image being detected by the hydrophones. Currents derived in this way are in excellent agreement with independent measurements obtained from moored instruments. (Contact: D.M. Farmer.)



Simultaneous measurements of bubbles in a tidal front in Haro Strait, obtained with a downward pointing Doppler sonar (left) and an echo-sounder (right). The Doppler measurements on the left show vertical speed deduced from acoustic backscatter by bubbles and other targets, calculated for various depths as indicated. The echo-sounding image on the right shows plumes of bubbles drawn down by convergence in the front. The bubble plumes attain speeds exceeding 25 cm s^{-1} .

The major activity of the remote sensing group at IOS in 1984 was the evaluation of the Fluorescence Line Imager, a new type of optical sensor with programmable spectral bands. It was developed for DFO purposes as part of Canada's space program. The sensor was flown by aircraft over freshwater lakes in June, over the Gulf of Mexico in September and over the Gulf Stream off the U.S. east coast in December. The resulting data are being analyzed at IOS using the image processing system and also by Moniteq Ltd., makers of the instrument. The flexibility of the instrument to form images and to record optical spectra from different targets is clearly demonstrated. The system noise level and calibration are being improved as part of the evaluation work. (*Contact: J.F.R. Gower.*)

Computing Services



During 1984, the workload on the Institute's Sperry 1100/60 mainframe computer increased significantly, reaching effective saturation during the prime shift with little idle time over-night. This large increase was due primarily to new scientists on staff engaging heavily in numerical modelling applications.

A long-range study of IOS computing requirements was begun in the spring. This led to a contract with DMR & Associates to assess the situation, examine whether IOS should continue to rely on a mainframe computer for its central computing facility or should utilize distributed super-mini computers with specialized peripherals and to make recommendations. The results of this study are expected in the spring of 1985.

Partly because of the mainframe overload, and partly because of a better fit to specific applications, nearly two dozen personal computers were acquired during 1984. These systems are used for instrumentation control, scientific data analysis of small data sets, word processing and administrative tasks. Thus the trend to distributed processing continues.

Field programs during 1984 continued another trend--the use of more intelligent sensors to gather data at higher rates and in larger volumes. This placed greater strains on all shore-based systems, especially the mini-computers. Plans were made to upgrade mini systems in several

areas to accommodate this increased processing requirement. (Contact: R.E. Johns.)

Ocean Chemistry



The major objective of Ocean Chemistry Division is to provide expertise, advice and a scientific perspective on both short-term and long-term problems associated with the chemical aspects of the oceanic environment through both monitoring and research activities. Five major areas are of prime concern: ocean pollution, ocean climate, ocean flux, ocean circulation and ocean productivity. The main effort is directed toward basic understanding of the long-term consequence of anthropogenic manipulation of the natural environment, but a balance is also struck by studying the short-term environmental impacts of societal intrusion.

Collaborative research is being carried out with international institutes, agencies and universities, including Woods Hole Oceanographic Institution, Scripps Institution of Oceanography, University of Miami, Pacific Marine Environmental Laboratory of NOAA, Shandong College of Oceanology and the Third Oceanographic Institute of the National Bureau of Oceanography in the People's Republic of China. Regionally, collaborative studies are being carried out with the Department of Oceanography at U.B.C., University of Victoria, Royal Roads Military College, Department of the Environment and the Pacific Geoscience Centre. External funding was received through the Office of Energy R & D and the International Development Research Centre.

Pollution Research

The major effort in 1984 concerned pollution in B.C. fjords with special emphasis on the Alice Arm/Hastings Arm area. A cruise was conducted to collect pore waters of sediments affected by mine tailings from past Amax mine disposals in Alice Arm and from the old Anyox copper mine into Granby Bay. Slag-tailings were dumped 50 years ago into Granby Bay and have been capped by recent natural sediments. A fibreglass catamaran with a plastic enclosure was tested on the cruise for *in situ* study of effects of tailing-contaminated sediments on the ecosystem and for sea water

chemistry. Lead 210 dating of sediment cores collected in the area and chemical analysis of the metals were completed for a final data report.

Metal-biota interaction was studied in cooperation with Habitat Management Division of DFO by analyzing the heavy metals and metal-binding proteins in Golden King crab (*Lithodes aequispina*) from Alice Arm and Hastings Arm. Sample manipulation was done inside a clean laboratory and protein chemistry was determined by a differential pulse polarographic procedure. Levels of copper in muscle and levels of copper and zinc in hepatopancreas of the crabs were statistically higher, possibly implying the old slag-tailings as a source. Metal-binding protein (MBP) concentrations were found in the hepatopancreas to be unexpectedly high at an average 1.4 percent of the dry-weight. In other areas of southern Vancouver Island, MBPs of the digestive glands of oysters had been correlated with contaminant sources of zinc and copper. (*Contact: J.A.J. Thompson.*)

Hydrocarbon work involved mainly the interaction of oil droplets, natural particulates, bacteria and phytoplankton by chemical analysis of the samples collected in the 1983 enclosure experiment of Prudhoe Bay crude oil dispersed with Corexit 9527. The finely-dispersed oil droplets generated with self-mixed dispersant rapidly became associated with large organic floc-like structures, possibly generated by bacteria. The oil/floc/bacterial aggregates were sedimented through physical entanglement with sinking diatoms. The straight-chain n-alkanes were removed completely from the oil within several days as indicated by both the quantification by gas chromatograph/mass spectrometer/data system (GC²/MS/DS) and by carbon 14-labelled n-hexadecane added as a tracer.

The GC²/MS/DS was upgraded with a computer-based laboratory information management system (LIMS) to conduct a study of the reliability of capillary column chromatography and the effect of solvent. Preliminary results indicated blind spots for detection by specific detectors insensitive under certain solvent conditions. (*Contact: W.J. Cretney.*)

Ocean dumping research in 1984 was directed toward providing guidance to obtain quality data and reporting. A highly-interactive, nationwide information exchange on metal analysis in sediments was conducted in cooperation with National Research Council, Environmental Protection Service and Bedford Institute of Oceanography with participating laboratories from government and the private sector. Technical reports were compiled on data interpretation for RODAC (Regional Ocean Dumping Advisory Committee) and on the development of pollution regulations and their application in scientifically-objective ways. Laboratory protocols

of validation of chemical analytical methods in sediment (ruggedness tests), measuring performance characteristics and storage tests were introduced into the routine procedures at IOS. (*Contact: R.W. Macdonald.*)

Trace Metals in Sea Water

Baseline levels of mercury in the waters of Alice Arm and Hastings Arm were found to be very low. Total, dissolved and particulate forms were measured using a sensitive technique to pre-concentrate the mercury on gold beads. The total mercury in both the tailings-contaminated waters of Alice Arm and the natural background waters of Hastings Arm was between 2 and 4 ng kg⁻¹ of mercury in sea water on the cruise in August 1983; in line with levels in Saanich Inlet but lower than open-ocean mercury values of 5 ng kg⁻¹ for the eastern Pacific Ocean studies during the CSS *Hudson* cruise in 1981.

A series of laboratory experiments were conducted to quantify the release of metals from (a) Alice Arm sediment contaminated by mine tailings; (b) Burrard Inlet sediment with high mercury of 3 ppm and False Creek sediment of 1 ppm mercury; and, (c) harbour sediment from Xiamen, P.R. China. A three-month storage study indicated little release of cadmium at 1 or 10 ppm of sediment in sea water, but a ten-fold increase at 100 ppm in the Alice Arm tailings-sediment study. Lead showed increases of up to a two-fold change for 1, 10, and 100 ppm of sediment in sea water. Mercury did not show a marked release in sea water from high mercury sediments. In the Xiamen harbour sediment study, lead, cadmium, copper, zinc, nickel, and cobalt were measured. Cadmium, nickel, and zinc exhibited no change; copper an increased constant level with increasing sediment/sea water ratio. Lead and cobalt indicated an initial release in the first 24 hours, then dropped to the same level after several days.

Intercalibration samples collected at Station P in 1981 were analyzed and compared to aliquots processed and analyzed at the California Institute of Technology. The soluble lead data obtained by clean laboratory and mass spectrometric technique both at IOS and Caltech showed good agreement for levels in open ocean waters of between 2 to 18 ng kg⁻¹. High lead values were found in sub-surface waters marked by high nutrients in waters influenced by the California Undercurrent flowing into the area during the summer. (*Contact: C.S. Wong.*)

Ocean Flux

Experiments were carried out under two international cooperative programs: Seafluxes and Parflux. The former was funded partially by the International Development Research Centre (IDRC) with a three-year cooperative program involving P.R. China and Canada to conduct marine ecosystem enclosed experiments (MEEE) at Patricia Bay, B.C. and in Xiamen, China. Participating institutes included the Third Oceanographic Institute of the National Bureau of Oceanography as well as the Shandong College of Oceanology both in P.R. China, the Department of Oceanography at U.B.C., and the Ocean Chemistry Division at IOS. The objective is to understand the pollutant dynamics in the marine environment. In the period August 7-24, 1984, 15 scientists and technical staff conducted an enclosure experiment at Patricia Bay on the behaviour and biological effects of mine tailings dredged from Alice Arm. Three large plastic enclosures of 60 m³ were used: one as a control, one with the addition of 2 kg and another with 12 kg in wet weight of tailings to the surface waters. Levels of dissolved, free and particulate metals (copper, cadmium, zinc, and lead) were measured, together with ecosystem parameters of nutrients, productivity, planktonic species and population, particle sizes and distribution. Lead was the only metal found to be released in significant amount from the tailings into the sea water. The major effect appeared to be that of the suspended particulates in sea water, causing a decrease in light transmission. The resulting slower photosynthesis, in turn, lead to a better balance between the organic production by the phytoplankton and the zooplankton grazers, both in phase. This is in contrast to the situation in the control bag, where the uninhibited photosynthetic production was much ahead of the population increase rate of the grazers, thus leading to disequilibrium and rapid detritus fallout. A scientific steering committee consisting of senior scientists of participating institutes from both countries and an IDRC representative met at UBC to review the progress of the joint program and for future planning.
(Contact: C.S. Wong.)

The Parflux sediment trap project was carried out as a cooperative venture with Woods Hole Oceanographic Institution. Three cruises, April 16-29, September 3-16 and November 5-25, to Station P (50°N 145°W) and along Line P retrieved and re-launched the automated moored sediment traps at 1000 m and 3800 m. Due to continuous usage for two and one-half years under rugged conditions at sea, a number of mechanical failures and electronic malfunctions led to a loss of a substantial amount of data and samples. However, the flux of material in 1984 appeared to be much lower than in 1983, which may be related to the El Nino year and/or a population

explosion of tunicates in the subarctic waters. In order to establish the production function for flux modelling, primary productivity measurements were carried out on the November cruise using metal-free carbon 14 techniques. Exceedingly high winter values of $200 \text{ mg C m}^{-2}\text{d}^{-1}$ were obtained, compared to the historical data of about $30 \text{ mg C m}^{-2}\text{d}^{-1}$ in the 1950s. (Contact: C.S. Wong.)

Marine Carbon Research Centre

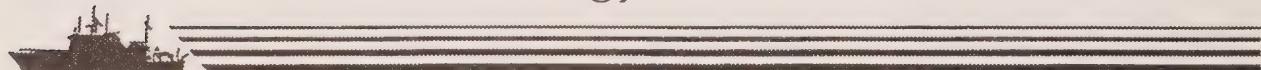
The Ocean Science and Surveys' Marine Carbon Research Centre (MCRC) at IOS, now in its sixth year, is focussing on the marine aspects of the global carbon dioxide (CO_2) cycle by conducting research, monitoring and modelling activities. The Centre took a lead role by conducting the second meeting of the Scientific Committee on Oceanic Research (SCOR) at Lake Arrowhead, California in May 1984. Fifteen participants from P.R. China, Japan, French Noumea, Australia, Germany, France, U.S.A., and Canada reviewed the technical and scientific basis for oceanic CO_2 studies, the global network design and the coordination of observational programs, with particular emphasis on a Pacific monitoring scheme in which our MCRC and the Pacific Marine Environmental Laboratory of NOAA formed the major components. The IOS program in 1984 was supplemented by funds from the Panel of Energy Research and Development to carry out some of the proposed SCOR work such as instrument development and creation of CO_2 standards, but an untimely cut left a few significant programs unfunded in the next fiscal year.

The ship-of-opportunity program was used on both the *Canada Ace* between Tokyo and Richmond, B.C. and the *Lillooet* between Brisbane in Australia, Noumea in New Caledonia and Richmond, B.C., to provide time-series data on atmospheric and ocean CO_2 , physical oceanography and productivity measurements in the Pacific Ocean for research and modelling. The PERD funds made possible shipboard testing of the automated partial CO_2 measuring system on the *Lillooet*. Two cruises, in May and in December, 1984 were manned by technical staff from Ocean Chemistry Division to investigate the source/sink relationship of oceanic CO_2 in the surface Pacific Ocean. A seasonal shift of the equatorial oceanic source of CO_2 was observed. A CO_2 standards laboratory was being set up with funds from PERD to measure CO_2 accurately by the state-of-the-art manometric method so that oceanic "snapshots" of CO_2 levels in the open-ocean can be established by repeating sectional measurements once every two to three years. (Contact: C.S. Wong.)

CO₂ research and modelling in 1984 concentrated on two aspects. The first was on setting up a diagnostic model of Canadian atmospheric CO₂ to study the relationship of sources and sinks from the Canadian land forest, Arctic and oceanic CO₂ reservoirs in the context of a global carbon cycle. Part of the work was published in the Journal of Geophysical Research on the trends of atmospheric CO₂ over Canadian WMO background stations at Ocean Station P, Sable Island and Alert. The second was on constructing a "biological pump" model to describe the mechanism of the removal of atmospheric CO₂ by photosynthesis in surface waters and the detritus sinking of both calcareous carbon (shell) and organic carbon (fecal pellets) into deep ocean storage, based on sediment trap data. (*Contact: C.S. Wong, Y. Chan.*)

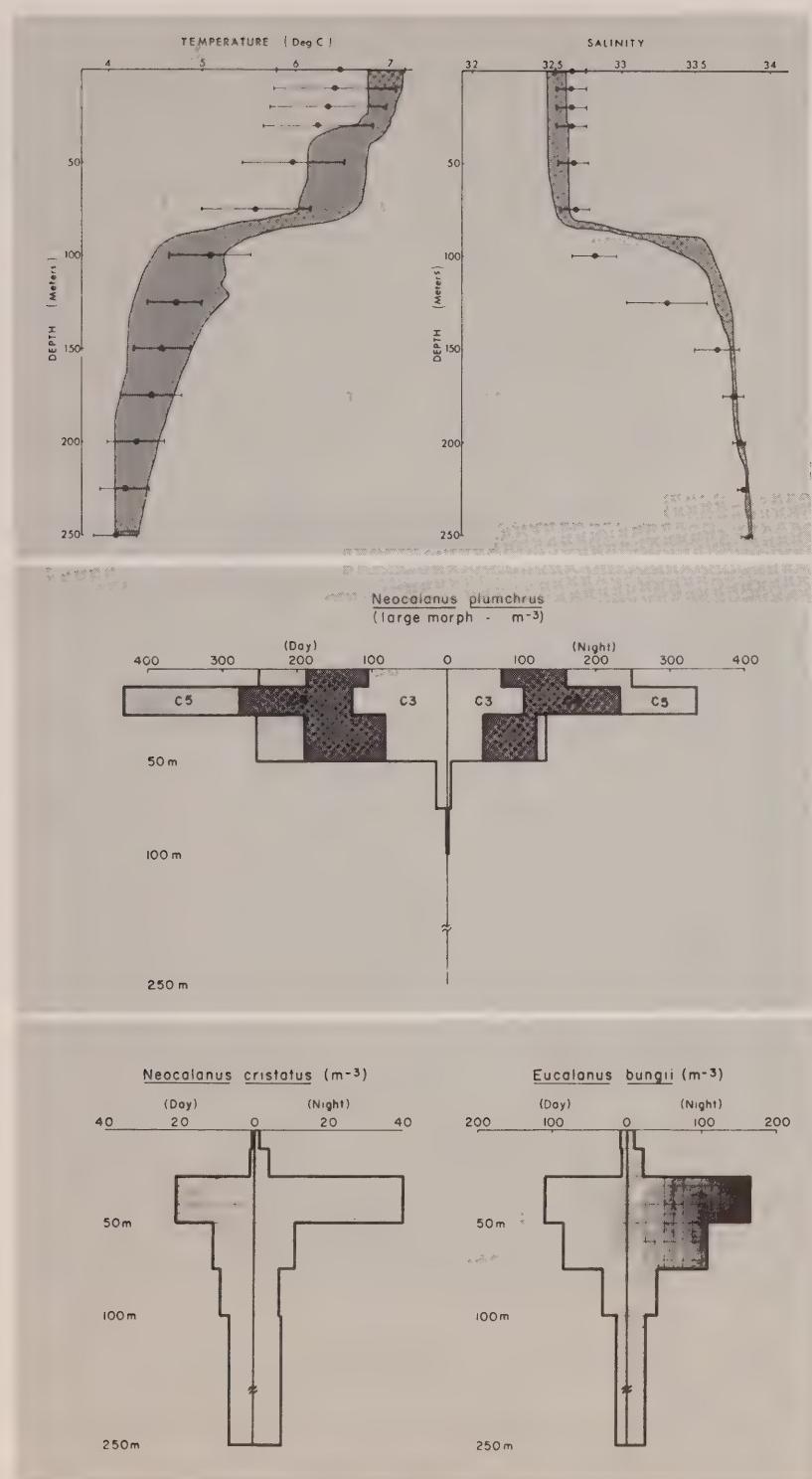
A program on the oceanic contribution to background acidity (Acid Rain) was initiated as a cooperative project with Atmospheric Environment Service. Air-sea exchange of freons, a chemical with greenhouse effects, was studied together with oceanic measurements of freons to trace intermediate waters as a joint thesis project with the University of Victoria. (*Contact: C.S. Wong.*)

Ocean Ecology



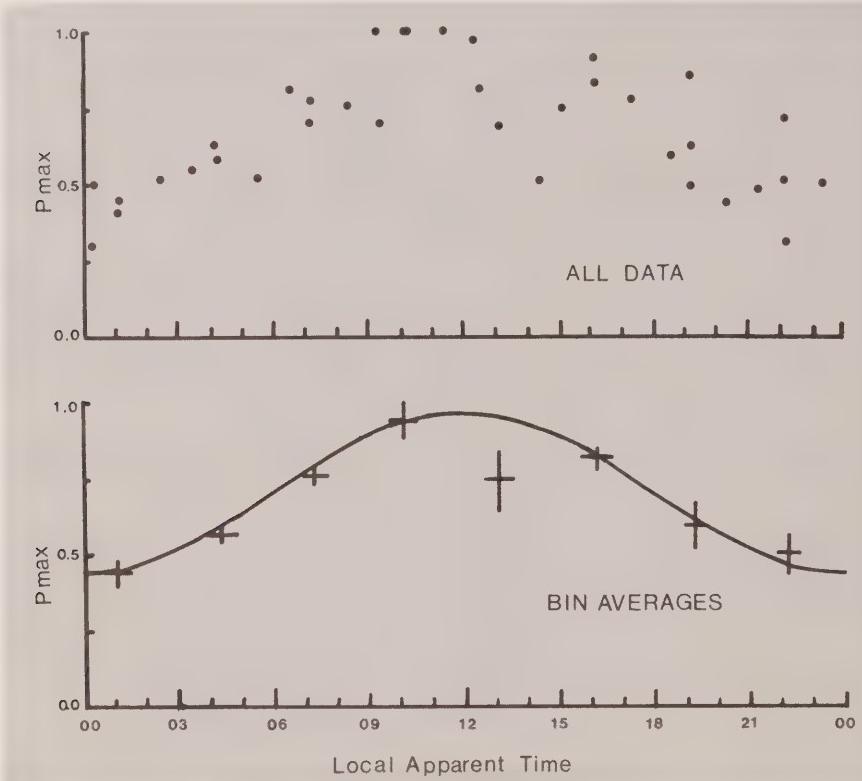
Plankton

In 1984 the Institute of Ocean Sciences participated in Project SUPER, an international study of the Subarctic Pacific ecosystem with its major emphasis on the balance between phytoplankton productivity and zooplankton grazing. Unlike most temperate and boreal regions, the Subarctic Pacific shows little or no seasonal cycle in phytoplankton biomass, despite an ample supply of dissolved nutrients and a strong spring and summer peak in primary productivity. The combined effects of high grazing capacity, spatial distribution, and developmental timing of the dominant herbivorous zooplankton have been hypothesized as the major factors limiting the phytoplankton crop. Project SUPER was designed to test the validity of this hypothesis. The Canadian effort included measurements of zooplankton spatial distribution and species composition (Mackas), phytoplankton growth as a function of light intensity (Forbes),

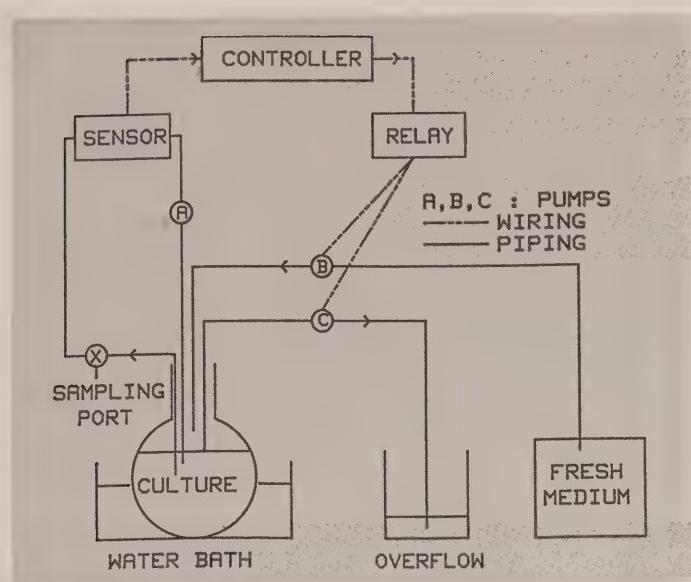


Water column structure and vertical distributions of some dominant herbivorous zooplankton species in the vicinity of Station P (50°N , 145°W) during May 1984. The upper panel shows temperature and salinity profiles. Shaded areas show the range of profiles measured in May 1984; circles and error bars show the mean and standard deviation of May samples 1958-1981. Lower panels show average day and night profiles of *Neocalanus plumchrus*, *Neocalanus cristatus* and *Eucalanus bungii*. Despite the relatively weak physical stratification in the upper 75m, the zooplankton showed strong vertical zonation with little day-night variability.

and vertical exchange of water and organisms within the upper layer (Gargett and Denman). The only strong stratification was associated with the halocline at 70-90 m. Despite the weak stability above this level, a small upper temperature gradient (depth variable between 25 and 50 m) largely prevented deep wind mixing. Much of the vertical exchange appeared to be associated with diurnal convection. Both the phytoplankton and zooplankton showed vertical population differences across the weak upper thermocline. This was particularly strong for the herbivorous zooplankton with *Neocalanus plumchrus* occurring day and night in the uppermost layer, and *Eucalanus bungii* and *Neocalanus cristatus* concentrated between the upper thermocline and the halocline. Most of the herbivorous zooplankton showed little or no diel vertical migration, and grazing potential was highest in the near surface layer where phytoplankton growth was fastest. (Contact: D. Mackas, K. Denman, R. Forbes.)



Daily cycle of photosynthetic capacity (P_{max}) from four 24-hour experiments in B.C. coastal waters. Top Panel: individual measurements of P_{max} , each normalized to the maximum value recorded in its experiment. Bottom panel: mean and standard errors of data, divided into 3-hour bins. A sine curve drawn through the data shows the form of the cycle and demonstrates the mid-day depression in P_{max} .



Schematic design for the microprocessor-controlled turbidostat. The culture vessel resides in a temperature-controlled water bath. Small subsamples of culture are pumped through the light sensor via piping circuit A. When the controller receives a signal that the culture is too turbid (and hence too concentrated), a relay is tripped to start pumping culture out through piping circuit C and replacing that with fresh medium through circuit B. Pumping continues until the desired culture concentration is achieved. As the time rate of volume overflow pumped is directly related to the rate of algal primary production in the culture vessel, a time series of the rate of production is obtained for the duration of each experiment.

Results from the SUPER cruise to the northeast Subarctic Pacific reinforced findings that the availability of dissolved nutrients is not the factor limiting primary photosynthetic production by phytoplankton, unlike many other oceanic regions. Rather, light intensity and quality, and their interaction with the cycling of phytoplankton cells by vertical mixing and internal wave motions, appear to control the realized primary production in adjacent coastal and oceanic waters.

For example, in several regions along our coast the maximum rate of photosynthesis at a given light level undergoes a definite daily cycle. To determine whether this cycle is a natural rhythm or whether it results from adaptations to recent light levels experienced by the algal cells, a microprocessor-controlled turbidostat for growing algal cultures under programmable light cycles of different frequencies and intensities was constructed. A turbidostat maintains the cultures at approximately constant cell concentrations by flushing out part of the culture when the light transmission through a small volume of the culture decreases due to an increase in the cell concentration and hence in the turbidity. Initial experiments with the turbidostat have been successful, although for certain species, if the dominant cell size in the culture changes markedly during an experiment, its optical transmission properties may also change. The result is that overall biomass concentration may change even though the optical transmission remains constant. Such effects can be monitored with particle sizing counters and hence can be accounted for in the turbidostat experiments. (Contact: K. Denman, R. Forbes.)

Benthos

Analysis of samples taken in Alice Arm after the cessation of deposition of tailings showed that those areas most seriously affected (nearest the mine) had recovered somewhat. Recolonization of sediments at line C involved polychaete worms, clams and amphipods. The picture was confused by a general reduction in faunal abundance at the less affected sites, but this was matched by a similar reduction in faunal abundance in Hastings Arm. There is an apparent progression from dominance by polychaete worms nearest the mine, and clams furthest from the mine. Samples were not obtained from these deep water stations in 1984, but Amax of Canada Limited sampled the shallower sediments closer to the mine outfall than the area covered by our study of 1983 and 1984. (*Contact: R.O. Brinkhurst.*)

The study of the benthos of the continental shelf off Vancouver Island progressed this year. Most of the study collection has been sent to various authorities for verification of local identifications, and the results for the major groups are now to hand. Much of the data has been retabulated to simplify the proposed report, with the complex data being archived. As soon as verifications are complete the report can be edited. (*Contact: R.O. Brinkhurst.*)

The study of squat lobsters (*Munida*) discussed in earlier reports has now progressed to the point that Fisheries Management is the primary sponsor of a project to see if this abundant, quite large animal can be exploited either directly as a food source or indirectly as food plus colouring material for salmonid aquaculture. At present *Munida* is a side catch of the prawn fishery that has to be sorted out and rejected. If retained and added to the unused parts of shellfish which are currently wasted, the combination might well provide a valuable by-product. (*Contact: R.O. Brinkhurst.*)

Samples of the benthos in Boundary Bay, B.C. were taken in a joint study with the Environmental Protection Service. Some question about the possible lasting effects of a toxic waste spill into Highland Creek and a tenuous connection to the death of grey whales in Puget Sound provided the initial stimulus for this project which fits into the Environmental Protection Service continuing analysis of disturbed and undisturbed local habitats. (*Contact: D.F. Moore.*)

Taxonomic studies of estuarine oligochaetes continued with a detailed review of the genus *Tubificoides* world-wide. Many sets of specimens were identified for outside agencies. A reconstruction of the evolution of the

Naidid family of oligochaetes, from a hypothetical ancestor to the species found today, is being carried out. The process of inferring the path of evolution has two stages. The first stage includes the careful examination and identification of specimens, determination of a set of characters that provide a precise description of all species, and the assessment of the characters for each extant species and the hypothetical ancestor. The information is then coded and analyzed using computerized mathematical methods for determining the most plausible phylogenetic tree, with the hypothetical ancestor at the root and the extant species at the tips of the branches. Phylogenetic trees give us insight into the process of evolution and provide a logical framework for the classification of living organisms.
(Contact: A. Nemec.)

Time Series Analysis

Observations of oceanographic variables, such as temperature and velocity dissipation, are found to deviate considerably from the usual assumption of a log normal distribution. This can lead to serious miscalculation of quantities of interest if a log normal distribution is used. Consequently, alternate representations are being sought. A contaminated Gaussian model and a nonlinear, non-Gaussian autoregressive model are being developed. (Contact: A. Nemec.)

The analysis of oceanographic time or spatial series frequently involves a search for periodicities. Standard spectral analysis and fitting of trigonometric functions requires that the observations be equally spaced with respect to time or space. This is not always possible. Methods for searching for periodicities in arbitrarily spaced observations are being investigated. (Contact: A. Nemec.)

The Division participated in two cruises, in June and August 1984, involving the discovery and sampling of hydrothermal vent fields in Explorer Ridge at 50°N, 130°W. Two specific problems were investigated:

The alvinellid polychaete *Paralvinella palmiformis* was selected for an exploratory study of metals and metalloids at hydrothermal vents. Results to date reveal that *P. palmiformis* accumulates elemental sulfur in a mucus layer on its epidermis. Shed mucus traps significant quantities of sulfide minerals, and may be important in the formation of mineral deposits at some vent sites.

Bacterial biomass in exiting vent fluid was related to fluid physiochemical properties. In addition to Explorer Ridge vents, samples were obtained

from a University of Washington cruise to Endeavour Ridge vents. Results suggest that conditions most favorable to sub-seafloor bacterial growth are created when the ascending hydrothermal fluid mixes extensively with intruding seawater. Future work will involve an expanded study of the coupling of physical, geochemical and microbiological processes below the seafloor in hydrothermal circulation cells. (*Contact: S.K. Juniper.*)

A large bacterial mat (100-500 Ha) in the lower reaches of Saanich Inlet was identified as primarily a monoculture of sulfide-oxidating bacteria. *Pisces IV* was used to study the influence of deep water renewal processes on the growth and distribution of these organisms. The mat was found to be remarkably dynamic in its ability to respond to fluctuating oxygen conditions and colonize the new habitat as made available by deep water renewal. (*Contact: S.K. Juniper.*)

Ocean Information



Ocean Information activities support the management, protection and exploitation of marine resources. Primary responsibilities include the collection and dissemination of oceanographic research data, the conduct of marine climatological analyses, the evaluation of environmental reviews, and the provision of information and advice through various committees to regulatory agencies. The Division also oversees the regional ocean dumping research program, provides information to OSS clients, media and the general public, and provides policy and planning support for regional operations.

B.C. Shorestation Oceanographic Program

During 1984, the B.C. Shorestation Oceanographic Program (lighthouse, monitoring program) provided surface-seawater salinity and/or temperature data from 18 locations. Preliminary examination of these data indicates that the large positive anomalies—with respect to the long-term mean—that characterized the “open ocean” stations in the first half of 1983 did not occur in 1984. Conditions at these stations (such as Amphitrite Point and Langara Island) have returned to near the “normal” state.

A considerable portion of the 1984 data was provided to agencies such as the International Pacific Salmon Fisheries Commission and the Pacific Biological Station as well as to private firms and individuals. The data from 1982 and 1983 were published in 1984. All the data obtained since the formal initiation of the program in the mid-1980's is now archived at IOS; programs for the processing and for the determination of some first-order statistics for these data at IOS were prepared during 1984 and are now in place. Preliminary work associated with the proposed updating of the 1972 report summarizing all data obtained since the program's inception is underway. (*Contact: L.F. Giovando.*)

Ocean Advisory Services

In 1984, IOS continued to provide considerable support to the Regional Ocean Dumping Advisory Committee (RODAC) and the Arctic Waters Advisory Committee (AWAC) by reviewing environmental terms and conditions for Arctic offshore exploration and Pacific coast dredging and dumping proposals. The Division also managed extensive R & D contractual work ranging from the quality evaluation of methodologies for marine sample analysis to ocean process studies pertaining to the release of heavy metals from dredge spoils. The annual Ocean Dumping Workshop which dealt with these and other topics, such as ocean sediment transport, was hosted by the Institute in December.

Division staff also contributed significant effort to numerous environmental assessment and marine planning committees and to inter-departmental initiatives. In particular, the Arctic Offshore Development Committee (ARCOD) was tasked with technical review and DFO position statements for Panarctic's Bent Horn oil production project, CMO's Lancaster Sound exploration plan and, the most demanding, Dome/Esso/Gulf EIS (Environmental Impact Statement) on Beaufort Sea hydrocarbon production and transportation. Based to a large degree on the scientific and technical evaluations of the Institute's researchers and hydrographers, the department's position on Beaufort development included the following overall recommendations: development should occur at a rate commensurate with the demonstration of safety, reliability and environmental acceptability; only demonstrated projects for subsea pipelines, offshore production facilities and year-round marine transportation of hydrocarbons may proceed at this time; and, expansion of offshore production and transportation should be considered only after the demonstration projects are shown to be safe, reliable and environmentally acceptable. These and other recommendations were heeded by the Beaufort Environmental Assessment Review Panel.

Several interdepartmental marine policy evaluations were attempted with the assistance of the Division related to such matters as abandonment of artificial islands and designation of Arctic waste dump sites.

The West Coast Offshore Development Committee (WESCOD) carried out detailed technical scrutiny of the Chevron and PetroCanada proposals for exploratory drilling in Hecate and Queen Charlotte Straits and other B.C. coastal waters. The industry documents were considered useful tools for identifying the major environmental issues. However, the restricted scope and the apparent scarce or unavailable oceanographic data necessitated a formal request of the proponents, through the West Coast Assessment Panel, for additional re-assessment and future research commitments.

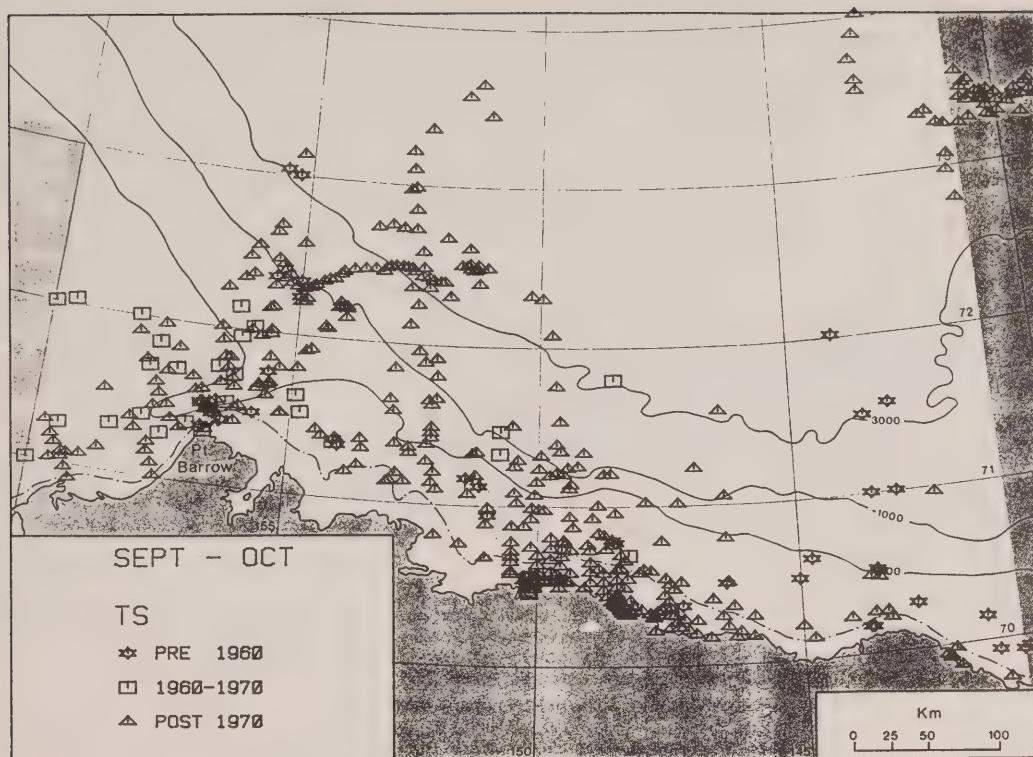
In related matters, ARCOD prepared the Department of Fisheries and Oceans' brief to the Special Senate Committee on the Northern Pipeline for its Offshore Transportation Study. (*Contact: L.F. Giovando, B.D. Smiley.*)

Ocean Data Services

Ocean Information Division's Data Compilation and Appraisal Program for the Arctic and Pacific coast published the seventh volume of a series of data inventories; this one pertaining to the currents, water levels, temperature and salinity measurements obtained in the Canada Basin and Arctic Ocean. Approximately 340 data sets (1883 to 1983) were compiled and described, resulting in a catalogue of station location maps, tabular summaries of time and location of all measurements, the actual parameters measured and the type of instrumentation, etc. The measurements were appraised or evaluated according to their collection methods and materials, storage and analysis. Unfortunately, necessary documentation was not forthcoming for the majority of the studies, even after considerable pursuit.

The design and implementation of the Oceanographic Data Information System (ODIS) continued as a Division priority, with the goal of providing rapid search and sort of multi-disciplinary ocean data set information using interactive computer graphics. Data inventories dealing with the physical, chemical and biological oceanography of Arctic and Pacific waters were formatted for inclusion in ODIS with the intention of providing off-site access to users by 1986.

Technical Records section acquired an additional 800 documents, bringing total holdings to approximately 2500, related to assessment, regulation and management of offshore waters (Arctic and Pacific coast). The bulk



The locations of all temperature-salinity profile data collected off the Alaskan coast in the months of September and October, excluding data obtained by Soviet investigators and U.S. oil companies for which locations are not available.

of these documents are considered as "grey literature", i.e., not scientifically refereed or published in recognized journals. Nevertheless, such information is useful in resolution of many issues regarding marine safety and environmental protection. (*Contact: B.D. Smiley.*)

Public Information

The fourth in a new series of IOS Annual Reviews was completed along with contributions to various departmental and inter-departmental annual reports.

A public display covering IOS activities was featured in the federal government pavilion at the Pacific National Exhibition and some elements were subsequently installed on-site at IOS.

The number of visitors to IOS continued to grow in 1984 making thrice-weekly tours now standard practice.

Media liaison was provided for special events such as the launching of the C.S.S. *John P. Tully* and *Pisces IV* dives and for on-going programs. (Contact: K. Glover.)

SHIPS





Launch day at Bel-Aire Shipyard in North Vancouver, October 27, 1984.

Ships



The Pacific Region Ship Division provided ship, submersible, launch and depot support for the 1984 scientific and hydrographic programs of the Institute of Ocean Sciences, other federal agencies and universities.

Of note in 1984 was the construction of the *William J. Stewart* replacement vessel. The contract was awarded to Bel Aire Shipyard Ltd. The keel was laid on January 30, 1984, and the launching took place on schedule on October 27, 1984. Named *John P. Tully* after the man known as "The Father of West Coast Oceanography", the vessel continues the trend to multipurpose ships, fulfilling both hydrographic and oceanographic functions.

The steel hulled, 69 metre *John P. Tully* will cruise at 12 knots with a range of 12,000 nautical miles and can accommodate 15 hydrographers or scientific personnel and a ships complement of 25. The ship is equipped with four 8.8 metre aluminum survey launches and a comprehensive navigation system that includes Sat Nav, Loran C, Omega and a doppler log in addition to radars and gyros. It is expected that the ship will be fully operational for the 1985 season.

C.S.S. PARIZEAU (64.3 m overall; 1929 tonnes)
Master: A.G. Chamberlain Chief Engineer: G. Winterburn

The *Parizeau* provided support for Ocean Physics, Tidal and Current Surveys, Ocean Chemistry, Department of National Defence, P.G.C., the University of British Columbia and the University of Washington. A large part of the summer was devoted to Hecate Strait surveys for Hydrographic Division. *Parizeau* also saw service as a primary Search and Rescue vessel during the herring roe season.

C.S.S. VECTOR (39.6 m overall; 505 tonnes)
Master: R.W. MacKenzie Chief Engineer: R. Pearson

The *Vector* provided support for Ocean Physics, Tidal and Current Surveys, Ocean Chemistry, EPS, P.G.C., University of British Columbia and Royal Roads Military College.

C.S.S. RICHARDSON (19.8 m overall; 78 tonnes)
Master: J. LeGarff Acting Master: M. Wheeler

The *Richardson* was tasked as a primary SAR vessel during the herring roe season and was used in support of field survey parties by Hydrographic Division.

M.V. PANDORA II; on charter (58.2 m overall; 1220 tonnes)
Master: S. Gulati Chief Engineer: R. Rogers/H. Doherty

The *Pandora II* provided support for Ocean Physics, EPS, Bamfield Marine Station, Pacific Biological Station (PBS), B.C. Provincial Museum and the University of Victoria, UBC and Simon Fraser. The majority of these programs were in conjunction with the submersible *Pisces IV*.

PISCES IV (6.1 m overall; 12 tonnes)
Chief Pilot: F. Chambers

Operating mainly from the charter vessel *M.V. Pandora II*, the *Pisces IV* made over 120 dives in support of Ocean Ecology, Ocean Physics, EPS, Bamfield Marine Station, PBS, B.C. Provincial Museum and various university programs. While working at the northern Explorer Ridge much new scientific information was gathered.

Barge *PENDER*

In addition to acting as mothership for the *Pisces IV*, the *Pender* was extensively used in field support for the Hydrographic Division. Surveys took place in Smith Inlet, Fish Egg Inlet and the Hardwicke Island area.

Institute Workshops

Normal repair and upkeep of the Institute's fleet of over 30 launches and small boats was continued throughout the year as was support to the *Parizeau*, *Vector* and *Richardson*. Mechanics were provided for both the *Pender* and *Parizeau* during their periods of hydrographic service. A new 7 metre tender for the submersible *Pisces IV* was constructed in the shops as well as a second rigid inflatable. Painting, fitting out and preparation for Canada Steamship Inspection of the 8.8 metre aluminum launches intended for the new ship is ongoing. Six of this class of launch are now in service. Both generators on the barge *Pender* have now been converted to a marine cooling system.

Deck Machinery

An on-going service program for winches and support equipment required for the various scientific cruises was maintained. In addition, major rebuilds of nine winches were undertaken. Some limited assistance to the Champlain Centre in Quebec was also provided.



MANAGEMENT SERVICES

Management Services



For Management Services Division, 1984 was a mixed year. In some areas the Division was able to accomplish tasks that had been outstanding for a long time, in others, lack of progress was evident and frustrating.

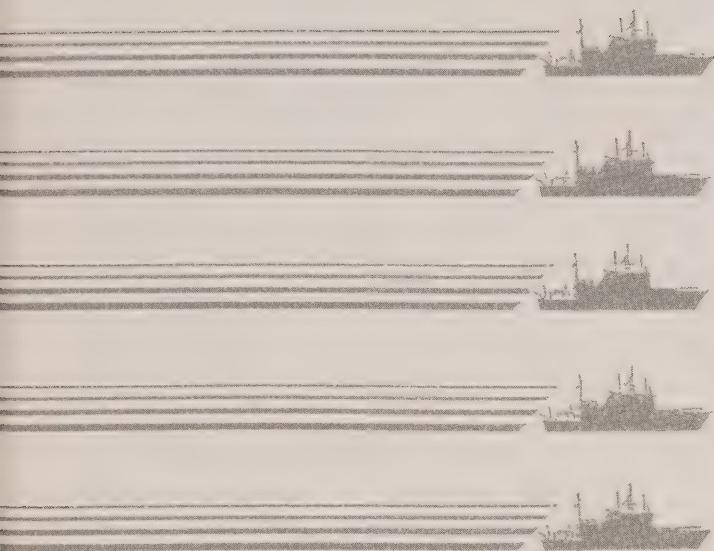
In the former, the Division administered an employment stimulation program for youth. At its peak this created an additional 86 jobs all directly associated with Institute programs. The large majority of these jobs were science related; however significant improvements to building and grounds were made through the FRED program.

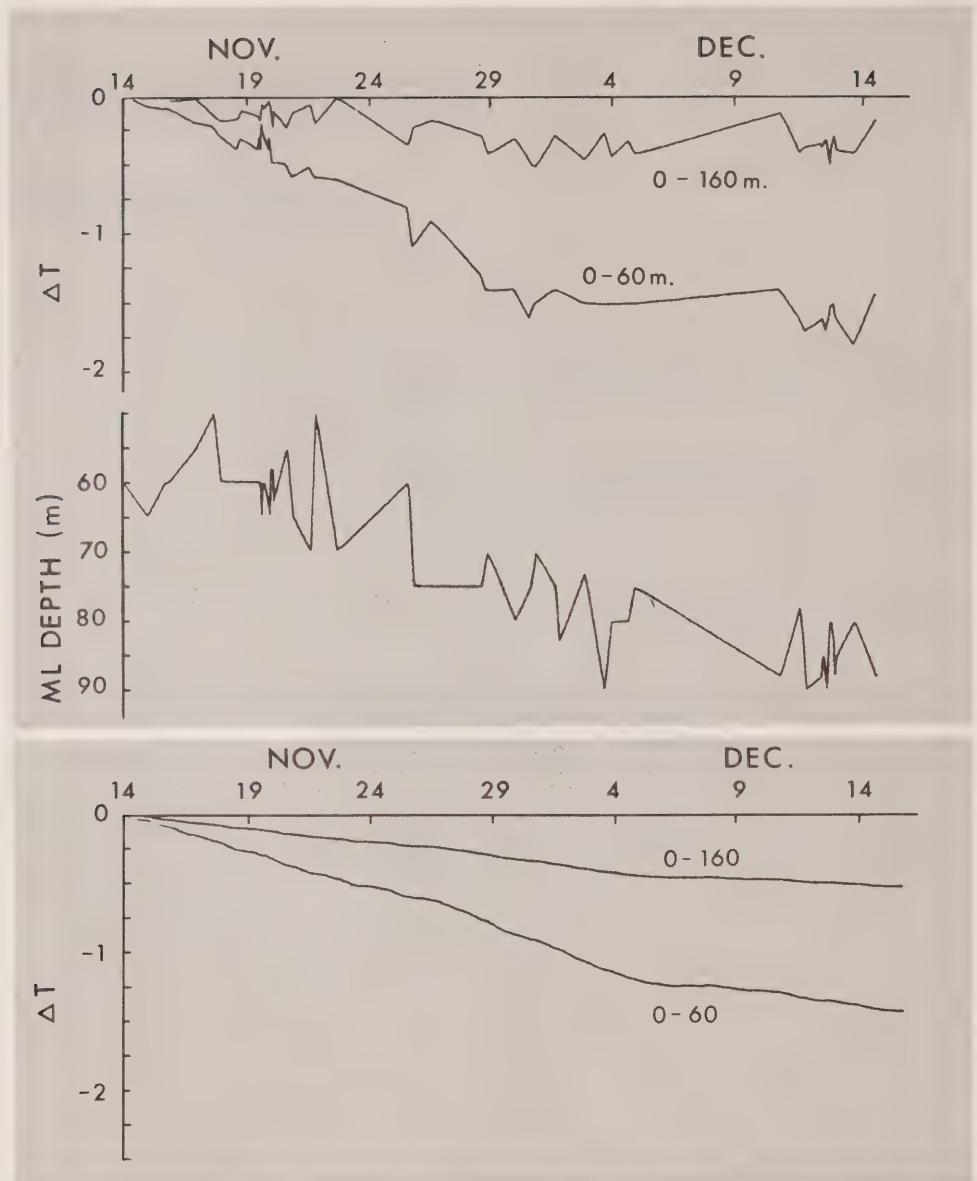
Exploiting the advances in office technology and integrated systems continued to have a high priority in the planning process for the Division. Improvements in level of service and in internal productivity coupled to better control are the basic objectives for new systems. Progress in this area in 1984 was somewhat disappointing. This year the Institute relied on the departmental central financial system discarding its 10 year old internal system. For most line managers this proved to be a less satisfactory arrangement. Improved departmental systems are being planned which hold promise but which do not provide immediate relief.

A further example of a significant improvement was the installation of an uninterruptable power supply to the Sperry mainframe computer. This system has been put to the test frequently since it started functioning and has proved reliable.

Being essentially a service division, the normal functions of the Division continued at an acceptable level despite a cut in resources (people and dollars) for the fiscal year 1984/85.

Department of Environment





The upper figure shows the observed changes in the average temperatures over the upper 60 and 160m of the ocean at Station Papa during the Storm Transfer and Response Experiment. The change in the depth of the mixed layer is also shown. The rapid variations are due to sampling biases introduced by internal waves; only the mean curve is significant. The lower figure shows the estimated cooling due to the computed cooling at the surface, due to evaporation and sensible and radiative heat losses. For the period November 14 to about December 5, the observed cooling exceeded the calculated cooling due to surface heat loss; for the remaining period they are about equal.

Atmospheric Environment Service



Atmosphere-Ocean Interactions

In order to model the global climate, it is necessary to understand the role of the oceans in the transfer of heat from the equator to the poles. Past studies of the North Pacific Ocean have led to contradictory results: some indicating a poleward heat transfer; others an equatorward transfer. Two different approaches to estimating the oceanic transfer are being pursued. The exchanges with the atmosphere lead to an estimation of the oceanic heat transport as a residual. Unfortunately, the best estimate of the uncertainties in the computations of the atmospheric-oceanic heat fluxes are such that the possible errors exceed the residual. Hence, although the data do indicate an equatorward heat transfer in the North Pacific Ocean, much confidence cannot be placed in the result. The data do show large differences from year-to-year, which are significant. These interannual variations are being further investigated.

An alternate approach is to investigate oceanographic measurements to deduce the oceanic transport more directly. Two sections across 35°N have been examined. They both show a transfer of heat toward the equator. The mean gyre circulation contributes very little to this transport because the depth-averaged temperature of the northward flowing water is almost the same as the southward flowing water. The principal transport is due to a meridional overturning with warmer water moving southward (relative to the gyre). Although both sections give southward heat transfer, the values for the two years are quite different. The effects of different sampling strategies are being investigated.

The upper ocean is particularly sensitive to direct atmospheric forcing; i.e., heat and momentum exchanges. During the Storm Transfer and Response Experiment (STREX), measurements of ocean and atmospheric parameters were made regularly and it is possible to monitor the atmospheric forcings and the oceanic response. It was found that for a period of two weeks, the ocean cooled more than the amount of heat lost at the surface to the atmosphere. This was a particularly stormy period, and the best estimates of oceanic advection (due to wind-induced currents) indicate that they are important to the balance. For the following period of 10 days, the oceanic cooling was approximately equal to the estimated

heat loss to the atmosphere. Thus, it appears that simple one-dimensional mixed layer models are inadequate to model the upper-ocean cooling during periods of strong winds. (*Contact: G.A. McBean.*)

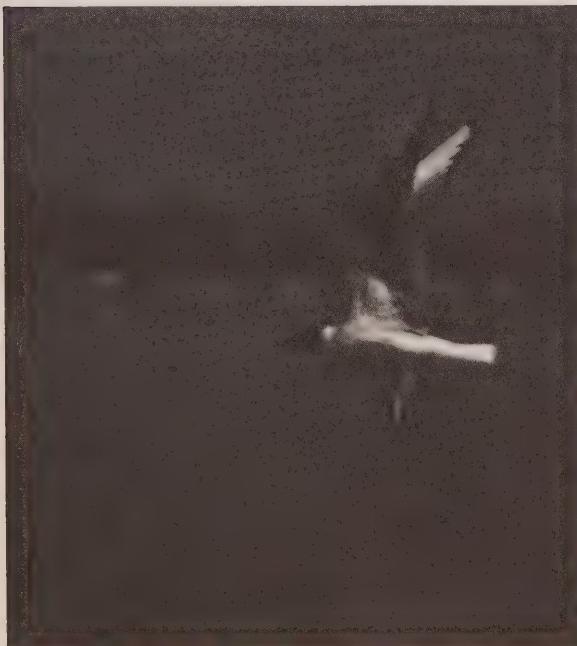
Canadian Wildlife Service



Research on seabirds continued in 1984 with studies on two gull species being initiated.

The first study was on the foraging of Bonaparte's Gulls in areas of upwelling and along fronts and tidal eddies in Active Pass. This is the first of a series of investigations planned to determine the significance of upwelling and density fronts as feeding habitats for seabirds on the British Columbia coast.

Bonaparte's Gulls visit Active Pass from late August to late November on their migration south from their breeding lakes in northern British Columbia, the Yukon and the Northwest Territories. The gulls visit Active Pass again from March until the end of May on their return to their northern breeding grounds from the U.S. west coast. At Active Pass, the gulls feed on euphausiids and amphipods. In areas without upwelling, the gulls' diet consists mostly of fishes. The gulls feed offshore by shallow plunge-diving or by dipping for and seizing their prey from the surface of the water.



Bonaparte's Gull

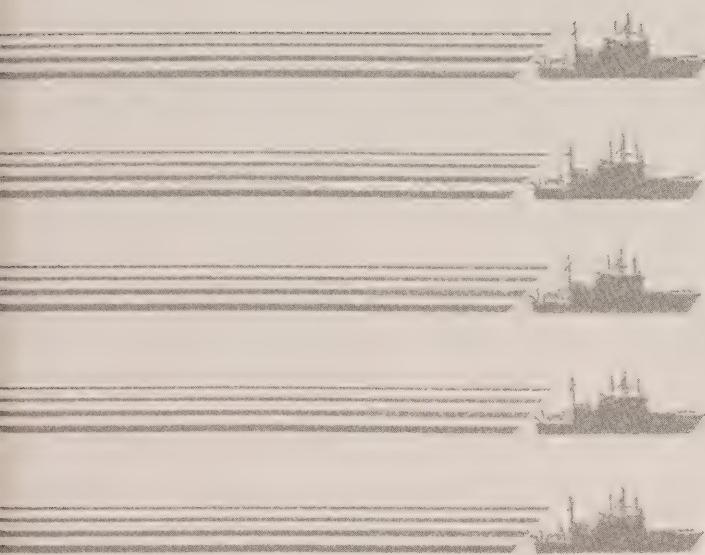
The objectives of this study are to determine 1) why thousands of Bonaparte's Gulls feed at Active Pass (apparently related to the abundance of zooplankton prey); 2) why feeding is restricted to the fall and spring; and 3) what time of the year euphausiids and amphipods are most available to the gulls in Active Pass. To attempt to obtain answers to those questions 1) gulls are collected each month that they are present in Active Pass in order to determine their diet; 2) zooplankton is sampled each month of the year (whether gulls are present or not) in both upwelling and control areas (east and west entrances to Active Pass); and 3) temperature and salinity profiles by a Beckman conductive salinometer and visibility by Secchi disk are determined at the sampling stations.

The second study involved the Mew Gull, which nests solitarily either on the ground of small islands or in trees along the shores of oligotrophic coastal lakes in British Columbia. The nesting habitat of Mew Gulls is being studied to determine 1) which lakes the gulls prefer for nesting purposes; 2) why the gulls select certain nesting sites on islands and not others; 3) their diet during their breeding cycle; and 4) their reaction to predators (large gulls and eagles). Answers to the above questions may provide insight as to why Mew Gulls nest solitarily—atypical nesting behaviour for gulls.

A report on the distribution and populations of pelagic seabirds in Hecate Strait and Queen Charlotte Sound was completed in December 1984. Surveys of seabirds in Dixon Entrance and on the west coast of Vancouver and Queen Charlotte Islands were initiated in October 1984. These surveys will continue until late 1985; the results will provide preliminary information about seabird distribution and populations on the British Columbia Shelf. (*Contact: K. Vermeer.*)

Department of Energy, Mines and Resources

Pacific Geoscience Centre



Geological Survey of Canada and Earth Physics Branch

Director's Foreword



The Pacific Geoscience Centre (PGC) continued to expand and improve its efforts in a broad range of marine and land-based geoscience disciplines over the past year. Staff and budget have increased and 50 people now work at PGC. With the additional resources have come increased responsibilities, notably the Offshore Boundaries Geoscience Program and the Frontier Geoscience Program. These programs have specific and relatively short term objectives, but they have also led to some very exciting fundamental scientific studies. The Boundaries Program continues until 1986. It is focussed on acquiring the data base and resource appraisal for the Shelf and Juan de Fuca Ridge which will be required for future offshore boundary negotiations.

The Frontier Geoscience Program will continue until 1990, at which time it will be reviewed and possibly renewed. The PGC component is directed primarily at the sedimentary basins that may have petroleum potential along the western margin of Canada and in the northern Yukon-Beaufort Sea region. Particular attention is being paid to Queen Charlotte Sound, Hecate Strait and the adjacent land areas. Renewed interest in petroleum exploration in the area has generated a need for additional geoscience data to support resource appraisal and the evaluation of potential hazards to development – such as earthquakes and sea-floor stability.

Juan de Fuca Ridge studies continued to be an important part of the PGC effort, with organization of, or involvement in, a number of cruises and submersible dive programs during the year. The SEABEAM swath bathymetric mapping in co-operation with NOAA (U.S. National Oceanographic and Atmospheric Administration) and the SeaMARC acoustic imaging surveys in co-operation with the University of Hawaii, the Lamont Geological Observatory, and the U.S. Geological Survey, have now provided seafloor maps and images of the ridge, equivalent to the topographic maps and aerial photographs available on land. Particularly exciting have been the discovery and initial mapping (with several university groups) of deposits of sulphide minerals associated with hydrothermal vents.

Along the margin, a major effort was made by PGC and a number of other government and university organizations in the Lithoprobe Program, an integrated geoscience study of deep crustal structure. The first phase, a traverse across Vancouver Island, was a notable success. The Vibroseis seismic reflection data clearly show the Juan de Fuca oceanic plate dipping at a shallow angle beneath the Island. Integrated with a wide variety of geological and geophysical studies, the seismic data have permitted a remarkably detailed picture of the deep structure and geological processes occurring along the western Canada convergent margin.

Of special significance to PGC and to marine geoscience in Canada in general, was the recent decision that Canada would become a member of the international Ocean Drilling Project (ODP). This project will lead, both to deep sea boreholes adjacent to Canada that will make critical contributions to our understanding of the Canadian offshore, and to the involvement of Canadian scientists in the forefront of marine geoscience around the world.

I have outlined above only a few of the many outstanding geoscientific studies that the staff of the Pacific Geoscience Centre have undertaken during the past year, and of which they can be justifiably proud. It has been an exciting and productive year. (*R.D. Hyndman*.)

Sedimentology



Estuarine and Marine Delta Sedimentation

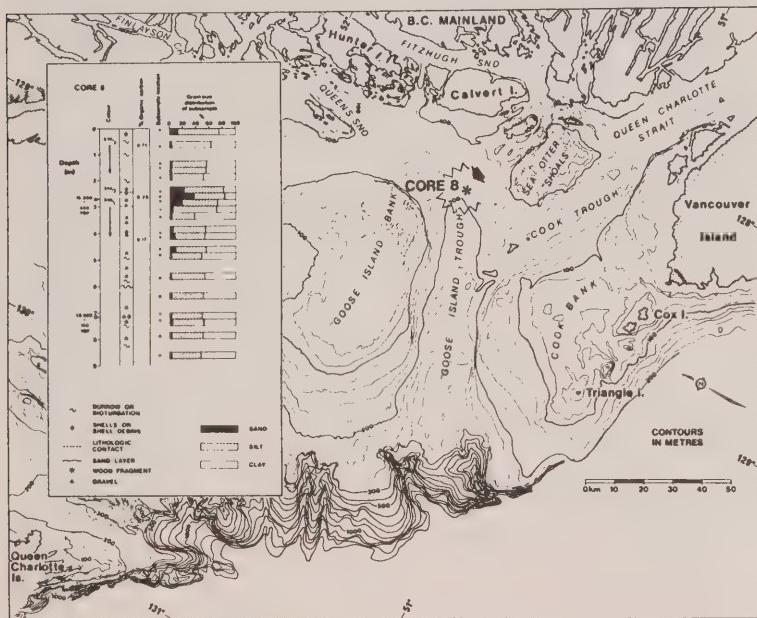
As in previous years demand remained high for geological data from the Fraser River Delta to help formulate environmental/engineering guidelines. The results of geological research have been applied to investigations by outside agencies relating to: the proposed Iona Island sewage pipeline; Westshore Terminals coal port expansion, the proposed B.C. Hydro Vancouver Island gas pipeline and design of a breakwater for the Tsawwassen Indian Reserve.

One highlight of the summer's field activities was the completion of an assessment of mechanisms influencing tidal creek erosion of ecologically

valuable eelgrass beds. The study area was adjacent to the Roberts Bank Coal Port on the Fraser River Delta. The work was performed in association with students from the Engineering (Geological) Department of U.B.C. The other highlight was the completion of the first phase of a coring program in the Fraser River Delta to decipher its structure, lithology and paleoenvironments. The work was performed by personnel of the Geography Department of Simon Fraser University in conjunction with PGC.
(Contact: J.L. Luternauer.)

Continental Shelf Sedimentation

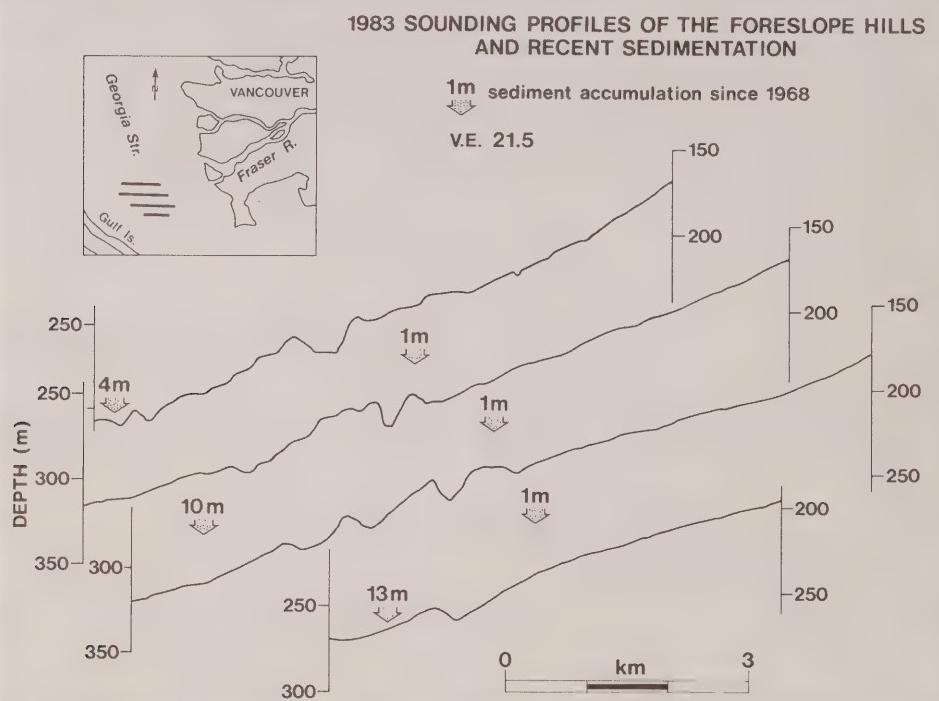
Research continued on the mapping of geological hazards to hydrocarbon exploration and production in Queen Charlotte Sound. This year's studies included employing side-scan sonar, Huntex Deep-Tow high resolution seismic profiling and piston coring. The data reveal major sand wave and boulder fields and suggest the presence of an extensive late Pleistocene debris flow. The debris flow could have been triggered by the collapse of



Lithographic description of Core 8 (asterisk) from Queen Charlotte Sound. The debris flow deposit consisting of a poorly-sorted, shelly, gravelly and sandy mud is identified by the spike in the sand concentration approximately 2.5m into core. This unit is recognized in other cores from the immediate region and on Hunter Deep-Tow records between coring sites. It overlies glacial deposits and is buried by post-glacial sediments probably derived from adjacent fjords. This debris flow deposit, which extends for over 50km² (area enclosed by saw-toothed line), was probably generated by submarine slope failure (at or near the site of the arrow) sometime after 12,000 years ago.

oversteepened side walls from a shelf ice-stream valley, by entrainment of older material in meltwater/tidal current torrents as glacial ice sheets retreated across the shelf, or by seismically triggered failure of older deposits on either Goose Island Bank or Sea Otter Shoals. The records also suggest that no major recent faulting or failure has occurred within the surveyed areas. (*Contact: J. Luternauer.*)

Modern sedimentation in Georgia Strait is dominated by the input from the Fraser River. Its submarine delta deposits extend nearly to the Gulf Islands. The Foreslope Hills, located midway between Sand Heads and Galiano Island, are a broad series of parallel ridges and troughs in the delta muds. They comprise a major slump structure (10 km N-S by 6 km E-W by more than 150 m thick). Detailed surveys made 15 years apart have been compared to assess changes in the seafloor morphology of this disturbed region.



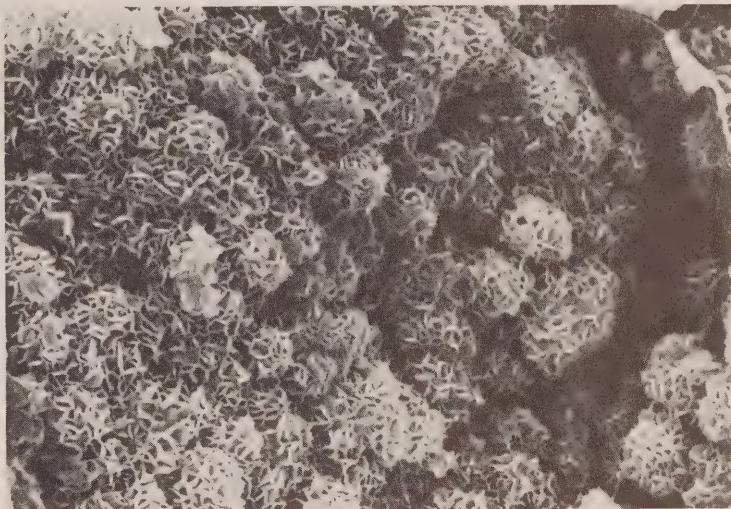
The sediment ridges have remained fixed in position and depth. However, the low lying troughs between the ridges and the regional foreslope above and below the ridges show vertical sediment accumulations ranging from one metre on the eastern (upslope) side to several metres on the western (downslope) side. There is also a pronounced increase in sediment

thickness at the downslope edge from +4 m in the north to +13 m in the south, implying a southerly sediment input, possibly from Roberts Swell. These bathymetric changes suggest high sedimentation rates of 0.07 to 0.8 m/yr. At these rates, the relief on the ridges will become subdued in a few tens of years, emphasizing the youthfulness of the seafloor instability of this region. (Contact: T.S. Hamilton, PGC; G. Eaton, CHS.)

A research project on the early diagenesis of shelf sediments, and specifically the formation of glauconitic smectite, was carried out on samples from the Vancouver Island shelf with Pierre Giresse of the University of Perpignan, France. It was found that these iron- and potassium-rich, green, sand-sized grains can develop within a few thousand years in areas of low sedimentation on the outer continental shelf. Recent formation of these minerals is more prevalent off British Columbia than on other continental margins because of the more readily available iron in unstable detrital minerals.



Typical glauconitic sand grain from Vancouver Island continental shelf.



Scanning electron micrograph of glauconitic smectite growing in voids in a sediment aggregate from the continental shelf west of Vancouver Island.

A survey of the nearshore geology and morphology of Virago Sound, northern Graham Island, was carried out in October/November using echosounding, side scan sonar and grab sampling. (Contact: B.D. Bornhold.)

Fjord Studies

A highly successful cruise was undertaken to Bute Inlet with participants from Louisiana State and Texas A&M universities. The aims of the study were to map the slope failure morphology in the upper part of the fjord, to obtain cores for geotechnical analyses and to interpret the history of, and processes involved in, submarine landsliding in the Inlet. It appears that massive failures of the fjord-head delta have taken place during the Holocene which have resulted in channel formation and deposition of sandy lobes in the deeper parts of the Inlet. Subsequent aperiodic events have transported sandy sediments through these channels and on to the basin floor up to 25 km from their source at the head of the fjord. Bute Inlet will be the site of a multiyear program involving further side-scan sonar mapping, shallow seismic profiling, coring, bottom-mounted current meters, sediment traps and transmissometer profiles in an effort to better understand the processes involved in such channelized sediment flows. (*Contact: B.D. Bornhold.*)

Offshore Studies

The study of sedimentation near the Dellwood Knolls continued, in cooperation with Bertrand Blaise and Henri Maillot of the University of Lille, France. It included x-ray diffraction, geochemical and textural analyses, scanning electron microscopy, radiometric dating and oxygen isotope determinations. The significant results to date indicate: very little geochemical influence on sedimentation by the nearby spreading axis; a somewhat greater abundance of smectite relative to other clay minerals in and near the spreading axis than outside it; the cessation of turbidite sedimentation in Dellwood Valley and Dellwood Basin, probably about 10,000 years ago, with the initiation of the Scott Channel system; small (0.2°C) thermal anomalies in the near-bottom waters in central Dellwood Basin; and, significant recent uplift of the Dellwood Knolls and their composite volcanic/sedimentary nature as shown by cores from the top of Southeast Knoll containing sandy terrigenous turbidites and ice-raftered debris. (*Contact: B.D. Bornhold.*)

Sedimentology Laboratory/Data Section

The sedimentology laboratory provides technical and analytical support for the Marine Geology Subdivision. Primary activities include: field collection of surficial sediment samples and data from offshore, fjords, continental shelf, estuaries and beaches; lithologic descriptions of samples; analysis of samples (approx. 1000 per annum) and archiving of

raw and processed samples.

The Data Section maintains an inventory of both field and analytical data which can be referenced by sample type, location, and analyses. The total number of samples on file exceeds 8500. Plots and print-outs of data and sample locations can be generated. Requests for data/plots/subsamples are filled for researchers within the department and outside, within Canada as well as internationally.

The current thrust for the laboratory is to move to micro-computer acquisition, storage, retrieval and manipulation of data directly from laboratory equipment and to transfer the existing data files from the Univac mainframe to a micro-computer in the lab. (*Contact: T. Forbes.*)

Bedrock Geological Studies



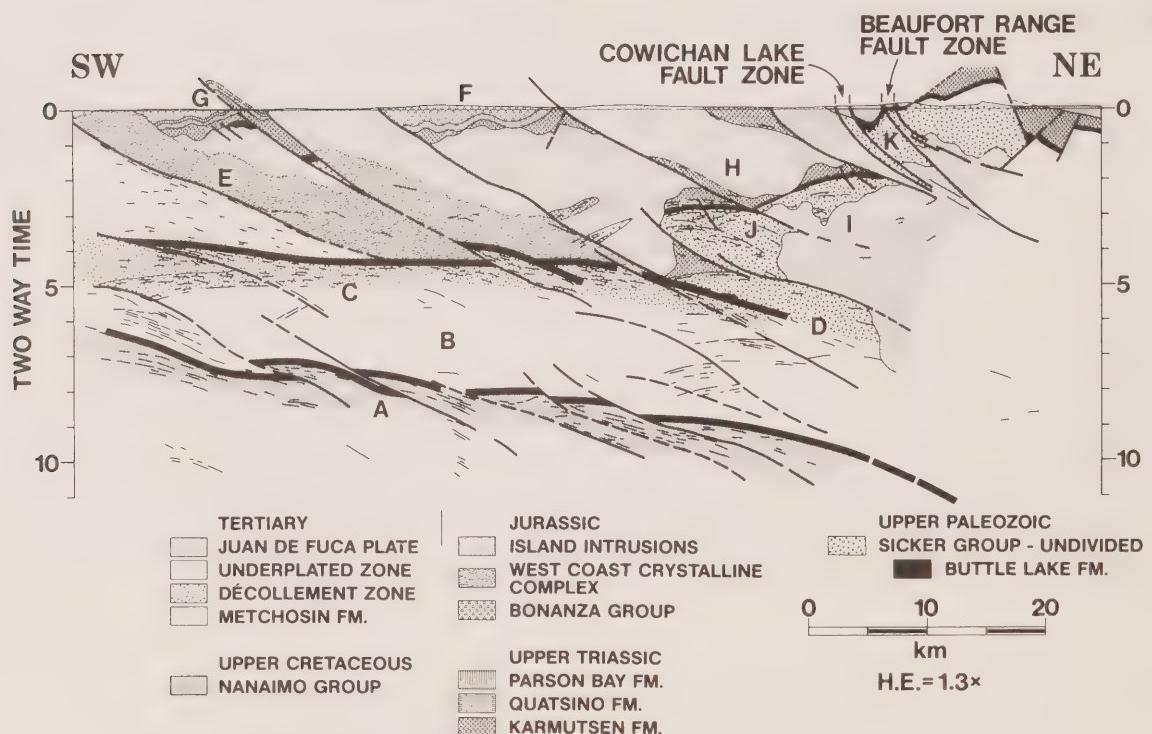
Lithoprobe – Southern Vancouver Island

Lithoprobe is a collaborative project involving an integrated program of geophysical, geological and geochemical studies designed to elucidate the nature of, and processes within, the lithosphere of Canada. The project is spearheaded by the Vibroseis technique which permits deep seismic sounding, to depths of as much as sixteen seconds (two-way time, Ca 50 Km). The program is funded jointly by the Natural Sciences and Engineering Research Council of Canada (NSERC) and the Department of Energy, Mines and Resources, and involves university, government and industry geoscientists in all phases from initial planning to final interpretation.

The reflection seismic program on Vancouver Island was conducted during late May and June of 1984. Supporting geological and geophysical studies were carried out by scientists of the Pacific Geoscience Centre and by several university geoscientists.

Initial results clearly show that the oceanic Juan de Fuca plate underlies rocks of the continental margin and descends easterly from a depth of about 24 km near the coast to 31 km beneath central Vancouver Island.

*Train of reflection seismic vibrators
on Vancouver Island.*



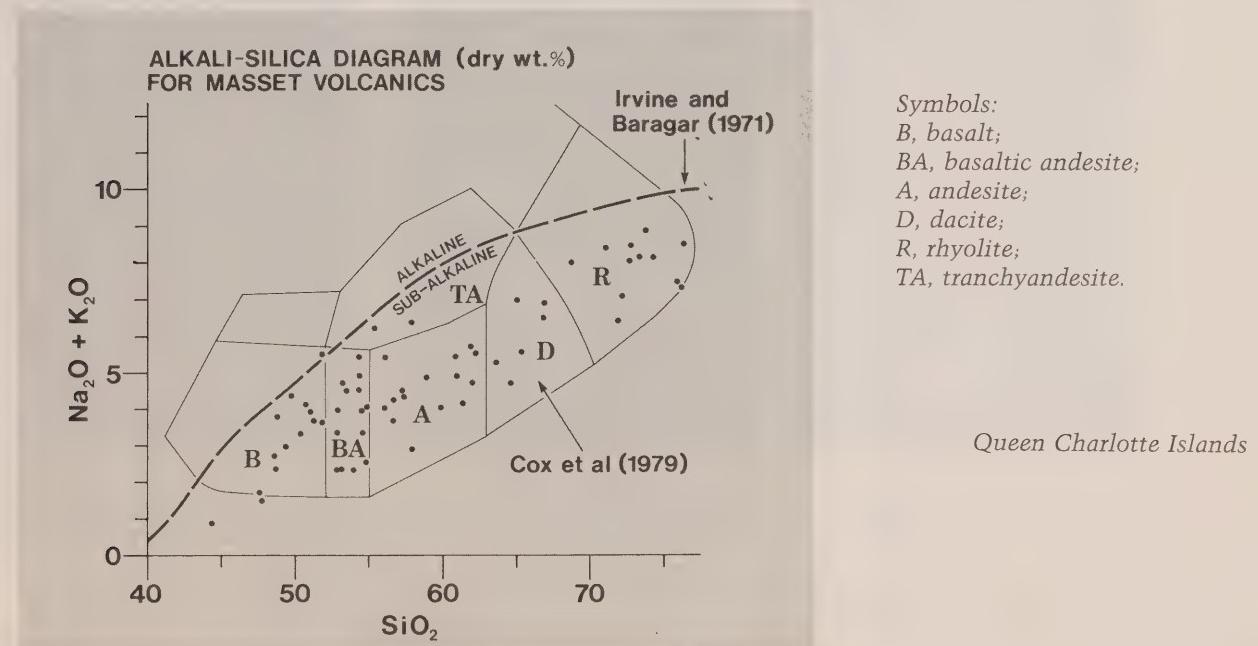
Preliminary interpretation of southern Vancouver Island transect from reflector geometry and surface geology.

The overlying rocks include two accreted crustal sections, the lower of possible pre-Late Miocene age and the upper of probable Eocene age. Between these two sections, a layered sequence appears to have acted as a zone of detachment for easterly dipping thrust faults that extend into the upper crust and project to mapped faults and intrusive contacts at the surface.

The dominant structural style of Vancouver Island that is emerging is one of east-west shortening by a combination of thrust faulting and folding of crustal and upper mantle rocks. The fault displacements decrease in age generally downwards and westwards. (*Contact: C.J. Yorath, A. Sutherland-Brown, M.T. Brandon, N.W.D. Massey.*)

Queen Charlotte Islands

The lavas of the Cenozoic Masset Formation are being studied as part of an ongoing program by the Geological Survey of Canada to investigate the volcanic rocks of the Insular Belt and the adjacent deep ocean. The Masset Formation is of particular interest because of its hydrocarbon shows and its dominant role in the Tertiary Stratigraphy of the Queen Charlotte Islands and adjacent parts of Hecate Strait and Queen Charlotte Sound. Understanding the origin and genesis of these lavas will provide constraints on the tectonic evolution of this part of the Continental margin.

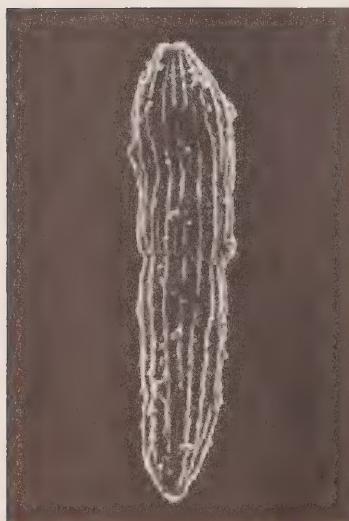


Palaeontology



Activities in Palaeontology and Biostratigraphy in 1984 centred around studies of the Jurassic foraminifers and stratigraphy of the Queen Charlotte Islands. Several new stratigraphic units have been recognized, some of which have significance as primary hydrocarbon source beds, so others may prove to be good stratigraphic hydrocarbon traps in subsurface.

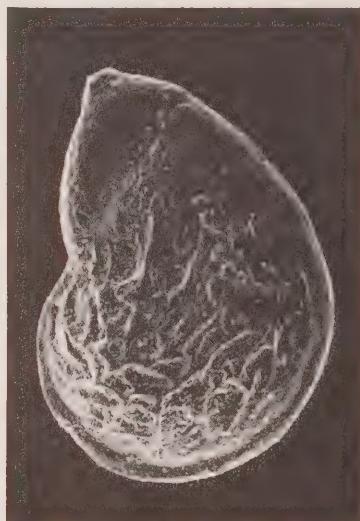
The Jurassic of the Queen Charlotte Islands spans approximately 40 million years of earth history in the interval 206 to 166 million years ago. The rocks are composed of a complex sequence of mixed volcanic and sedimentary rocks which nevertheless carry rich fauna of both macro and microfossils. It is currently estimated there are about 400 species of foraminifers throughout this section, which while providing an excellent means of dating the rocks, indicate the environments in which the rocks were deposited. The sizes of the illustrated microfossils vary from 0.5 to 1.5 mm in length. (Contact: B.E.B. Cameron, M. Johns.)



Nodosaria opalini Brand



**Frondicularia bicostata
bicostata** d'Orbigny



**Lenticulina d'orbignyi
(Roemer)**

Juan de Fuca Ridge Mapping



Detailed SEABEAM mapping efforts were continued in a cooperative effort with S. Hammond of NOAA on the production of several new 1:50,000, 10 m contour map sheets and 1:250,000 regional compilations over the northern Juan de Fuca Ridge system. The maps have already been put to use both for direct tectonic interpretation and as base maps for geophysical studies using lowered, deep-towed, and bottom-deployed instruments, and using the research submersibles *Alvin* and *Pisces IV*. (Contact: E. Davis, R. Currie, B. Sawyer.)

Mapping of seafloor features is also continuing at a finer scale, using the deep-towed SeaMARC I acoustic imaging system in cooperation with W. Ryan, Lamont Doherty Geological Observatory. Images produced by this system are much like aerial photographs on land, and features of sizes down to a few metres can be resolved. Extensive surveys carried out over the northern Juan de Fuca Ridge and Explorer Ridge have yielded many surprising results.



Scanning electron microscope micrographs of Jurassic foraminifers of the Queen Charlotte Islands.

Citharina flabellata (Gümbel)

Extensive lava flows are common on the seafloor near the ridge crest. Sources of these flows are both at the ridge crest itself and on the flanks of young seamounts. Some flows extend 20 to 30 km. The shape and surface morphology of the flows are strikingly similar to those of subaerial basalt flows.

A great number of hydrothermal features are also observed, many of which are along normal fault scarps, others of which are situated over well sedimented unfaulted crust. Some of the constructions have substantial relief (50 m) and extent (300 m) and have been found to be currently active (see Marine Studies). (*Contact: E. Davis, N. Massey, B. Sawyer.*)

Seismological Service



The Seismological Service provides earth scientists, civil engineers, resource development industries and the public with basic earthquake data and with research information concerning natural and induced earthquakes, ground motion seismic risk, earth structure, and nuclear explosions. This is accomplished through a network of seismological stations, including standard and regional stations, two telemetered arrays, strong motion accelerographs and special installations.

Seismic Networks

The Western Canada Telemetered Network (WCTN), established to provide centralized, on-line monitoring of seismicity in southwestern British Columbia, was expanded in 1984 by one station in Strathcona Park. Eighteen stations are now being recorded at the Pacific Geoscience Centre, including three stations of the University of British Columbia network. One regional station has been added to the Queen Charlotte area network at Langara Island. (*Contact: D.H. Weichert, G.C. Rogers, R.B. Horner and M. Bone.*)

The strong motion seismograph network in western Canada consists of instruments designed to operate and record ground acceleration only when very strong earth motion occurs (1/2% of normal gravity or larger). During 1984, one new instrument was added in the Queen Charlotte area for a total of 36 accelerographs. A review of the growth and current status of

the Canadian strong motion program was made for the International Association of Seismology and Physics of the Earth's Interior. The Miramichi earthquake series of 1982 has given a significant impetus to the development of the Canadian strong motion instrumentation program. The accelerograph network of the National Research Council is now under the direction of Earth Physics Branch and extra funding has become available for upgrading the western network.

Special Earthquake Studies

The Beaufort Sea special seismicity study continued through the better part of the year. Dome Petroleum withdrew from the cooperative project and the four Beaufort Sea shore stations were closed in July. When alternate funding became available in the fall, stations at Komukak Beach, Shingle Point and Nichelson Point were reopened. These are telemetred to the standard seismograph station at Inuvik.

An isoseismal map of the 1949 magnitude 8.1 Queen Charlotte Islands earthquake was completed. The data are sparse, but clearly show this event to be much larger than the 1906 San Francisco earthquake. (*Contact: G.C. Rogers.*)

An investigation of the microearthquakes recorded on the Queen Charlotte Islands since the first seismograph was installed in 1970 showed very little activity east of the Queen Charlotte Fault, although last year's field experiment clearly did record some activity in that region. (*Contact: G.C. Rogers.*)

Western Canada Seismicity

The Pacific Geoscience Centre is responsible for locating all earthquakes recorded in western Canada for inclusion in the national earthquake data file. Data from 51 stations are now processed, and some 750 earthquakes were located during the year. During 1984, 18 earthquakes were reported felt in western Canada. These included one on southern Vancouver Island, one on the Queen Charlotte Islands, five in southern British Columbia, four in northern British Columbia, four in southwestern Alberta, and three in Saskatchewan. No earthquakes were reported felt in the Yukon Territory. The largest earthquake to occur in western Canada during the year, magnitude 5.8 on June 24, was centred south of the Queen Charlotte Islands. The earthquake on the Alberta-British Columbia border on February 11, magnitude 4.7, was the most widely felt. No damage was reported in western Canada for any earthquake in 1984. (*Contact: R.B. Horner, G.C. Rogers, D.H. Weichert.*)

Seismic Risks

PGC continues to supply site specific seismic risk calculations based either on the extreme value method of Gumbel, as specified in past versions of the National Building Code of Canada; or alternatively, requests can be made for the new method that will be introduced in the 1985 edition of the National Building Code. (*Contact D.H. Weichert.*)

Gravity



The principal mandate of the Gravity Service is to establish the shape of the geoid in Canada to the highest standards and to determine the value of gravity on a regional basis over the Canadian landmass and offshore areas. The regional gravity data provide information for both the determination of crustal structure and the evaluation of resources and are critical to the operation of inertial navigation systems.

The focus of regional land gravity surveys was shifted this year to the Yukon Territory where approximately 450 new gravity stations were established along a 100 km wide corridor centred on the Dempster Highway between Dawson City (64°N) and Fort McPherson (67°N). In addition, regional gravity profiles were established across the Eagle Plain Basin between the Dempster Highway and the settlement of Old Crow and in the Northwest Territories along the abandoned Canol Road from Norman Wells to MacMillan Pass.

Detailed gravity transects of about 1 km spacing were conducted across the Tintina Fault in the vicinity of Ross River and near Dawson City. The detailed coverage at both sites will provide a better understanding of the fault geometry in the upper crust.

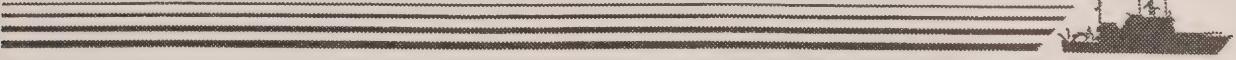
A detailed transect was also made across the seismically active Richardson Mountains at about 67°N. Preliminary results show a Bouguer anomaly high of 35-50 mGal present along the spine of the mountain range indicating the likely absence of an underlying crustal root.

Approximately 85 gravity stations were visited along a detailed transect

of Vancouver Island between Dunsmuir and Pachena Bay as part of project LITHOPROBE.

Due to the cancellation of the resource charting cruise, there was no offshore gravity program in 1984. (*Contact: J. Sweeney, D. Seemann.*)

Thermal Studies



The earth's temperature influences both rock properties and geological processes. Thermal data, particularly surface heat flux, are important indicators of deep tectonic processes and the structure of the earth's crust. Most active tectonic processes that result in mountain building, earthquakes and volcanism, originate from thermal energy. Geothermal data also are needed to calculate the degree of maturation of hydrocarbons. In addition, the earth has considerable economic potential as a heat source for geothermal energy.

Measured thermal parameters include surface heat flux (the result of vertical temperature gradient multiplied by the thermal conductivity of the rocks) and heat production from natural radioactive decay in crustal rocks (for example: thorium, uranium and potassium). Studies cover a wide range of geological and geophysical interests—from heat flow, heat production and thermal processes in the deep sea floor to the discovery and development of geothermal energy resources in western Canada.

Land Studies

Geothermal data were acquired along the LITHOPROBE profile on Vancouver Island as well as in holes drilled for mineral exploration in areas near Clearwater, Banks Island and Anyox. Samples for heat generation measurements were collected from intrusive bodies in southeastern B.C. Gamma-ray spectroscopy measurements on cores near the shelf indicate that depositional age estimates depend on the half-life of 226Ra rather than 230Th. H. Villinger is testing a pulsed needle technique in the laboratory for rapid measurements of the thermal conductivity of chip samples.

A manuscript on heat flux in southwestern B.C. shows that the Intermontane and Omenica Crystalline Belts form a single heat flow province with a high heat flow, similar to areas of the Basin and Range province to the south. Low heat flux under the Insular Belt and Coast Plutonic Complex is the result of subduction. An abrupt change in heat flux over a distance of 20 km along Jervis Inlet is thought to reflect a thermal boundary above the zone where the hot asthenosphere flowing at first toward and then down with, the subducted oceanic crust and entrapped sediments, starts to significantly heat the subducted material. A data file containing all the results of heat generation measurements up to 1984 was published.

(Contact: T. Lewis, W. Bentkowski.)

Marine Studies

The collection, analysis, and interpretation of heat flow data from the Jurassic sea floor of the Western Pacific are well under way as part of a continuing study of the thermal history of old oceanic lithosphere with workers from University of Texas and University of Washington. The heat flow is generally higher than that which can be explained by any simple cooling history. A widespread reheating event may be the cause of the anomalously high heat flow. (Contact: E. Davis, H. Villinger.)

Heat flow studies have been conducted over a well sedimented axial valley of the northern Juan de Fuca Ridge. A number of active hydrothermal features have been identified and basement (hence probably groundwater) temperatures beneath the sediment fill have been established to be in excess of 300°C. (Contact: E. Davis, H. Villinger.)

Geomagnetism

The Geomagnetic Field

The earth's geomagnetic field varies both spatially and temporally. This inherent variability is exploited in a variety of ways. To be utilized for navigation, the magnetic field and its gradual change with time must be determined as a function of latitude and longitude. Spatial changes in the magnetic properties of rocks also lead to spatial variations in the magnetic field which can be used as signatures of structure, composition and the thermal history of crustal rocks. Short-period temporal changes in the

magnetic field are measured to resolve subtle field variations as encountered in exploration geophysics.

In Canada, the geomagnetic field is monitored continuously at 13 primary observatory sites. As part of this Canadian Geomagnetic Network, PGC operates the Victoria Geomagnetic Observatory on property at the Dominion Astrophysical Observatory. (*Contact: L. Law, D. Auld.*)

Geomagnetic Variations

Temporal variations in the earth's magnetic field provide a source of electromagnetic energy with which to probe the earth's electrical conductivity structure. Electrical conductivity is an important parameter in understanding the active tectonic regions on the west coast. Deep zones of high conductivity, related to high temperatures and partial melting, determine the maximum thickness of the cold lithosphere riding over the asthenosphere. Conductive zones at shallow depths occur in regions with geothermal resource potential.

A magnetotelluric survey across central Vancouver Island, along the northern two Lithoprobe lines, obtained data at eighteen sites with the Phoenix geophysics system. The survey provided important new information about the electrical conductivity structure of this subduction region.

An innovative method has been developed, in cooperation with the University of Toronto, to determine the electrical conductivity of the seafloor. The Magnetometric Off-Shore Electrical Sounding method (MOSES) utilizes a source field produced by an electric current transmitted by a long wire, extending from the sea surface to sea floor, and measured by an ocean-bottom magnetometer. Using this method, the resistivity and thickness of the sedimentary section beneath Bute Inlet was determined to be 1.9 ohm-metres and 560 metres respectively. The MOSES method was also used over two areas near the Juan de Fuca Ridge, at the central and southern end of Middle Valley, at a depth of 2200 metres. Analysis of the data from the central area gave a resistivity of about 0.8 ohm-metres and a thickness of approximately 1800 metres for the sediments. At the southern end of Middle Valley the sediment cover was only 200 metres. The underlying fractured basalt layer, with a resistance of 9 ohm-metres, extends to a thickness of over 1000 metres in this area.

A controlled source sounding of a young basalt flow in the axial valley of the Juan de Fuca Ridge was carried out using the United States deep submersible Alvin to position the seafloor instrumentation.

The monitoring of changes in apparent resistivity related to the increase in tectonic strain in central Vancouver Island continued at two sites in the area. To date, there has been no significant change observed in the resistivity data over the four-year duration of the experiment. (*Contact: L. Law, J. DeLaurier, D. Auld, D. Nobes.*)

Paleomagnetism

The paleomagnetism of rocks records the variations in directions of the geomagnetic field in the geological past. The intensity of the ancient field is also recorded, but is difficult to observe and can only be obtained in very favourable circumstances. The principal application of paleomagnetism is in tectonics — the study of the motion of continents, the opening and closing of oceans and the origin of mountain belts — but it is also used widely in many problems of stratigraphic correlation, the origins and thermal history of rocks and in the source and origin of magnetic anomalies.

Paleomagnetic work at PGC is concerned with the tectonics of the Cordillera and the western Arctic and with magnetostratigraphic studies. During the last decade, geological and geophysical studies have shown that the Cordillera comprises a number of distinct crustal blocks. Vancouver Island is part of one such block. Paleomagnetic work has shown that these blocks have been transported from the south by distances over 1000 km; much of central British Columbia once being in the latitude of California or further south. Indeed, Vancouver Island could have moved northward by over 5000 km relative to North America and may have originated on the other side of the Pacific Ocean. The western Cordillera, therefore, appears to be a collage of small crustal fragments that originated elsewhere, were carried over large distances, and finally were glued to North America. This discovery has led to a profound revision of ideas about the origin of this and other mountain belts.

Two major programs are underway. The objective of the first is to collect a suite of rocks along a traverse across the Cordillera from Vancouver Island to the Rockies in order to determine the relative latitudes of the various crustal elements at one geological instant in time; namely the Middle Cretaceous epoch near 100 Ma ago. The second program calls for a traverse across the northern rim of the Sverdrup Basin at Ellesmere Island.

Further collections of Cretaceous and Permian rocks were made in Axel Heiberg in 1984 in collaboration with the Institute of Sedimentary and Petroleum Geology (ISPG), and of Cretaceous and Tertiary rocks in

collaboration with Geological Survey of Canada, Vancouver. Notable results are from a Cretaceous intrusion near Prince Rupert (Smith Island gabbro) which yields a multiplicity of reversed and normal magnetizations commonly present in the same specimen. Work by a student from Carleton University yields a secondary magnetization of probable mid-Cretaceous age in Triassic rocks of the Quesnel Terrane. All those Cordilleran mid-Cretaceous data indicate a displacement of the western Cordillera by 2000 km to the south at that time. (*Contact: E. Irving, P.J. Wynne.*)

Geodynamics



The principal subject of study for Geodynamnics in the active region of the west coast of Canada continues to be contemporary crustal deformation. One main objective of this is to establish realistic dynamic models of crustal plate behavior at plate margins and utilize these in the study of local earthquakes.

Currently, three geodetic measurement techniques are being applied in the area of central Vancouver Island in order to monitor on-going crustal deformation: precise gravity, vertical control and horizontal control surveys.

Semi-annual surveys of the central Vancouver Island precise gravity network, which were initiated in 1977, were again completed during 1984. Most of the observed gravity changes to date can be related to changes in water levels of the Strathcona Reservoir or changes in local groundwater levels. The past year has also seen significant improvements in the gravity data handling capability at PGC. Input to the national database in Ottawa and network analysis of any contained data can now be carried out directly from the west coast.

Precise elevation measurements were made by the Geodetic Survey of Canada along Highway 19 between Parksville and Kelsey Bay. Portions of this route had been levelled before in 1930, 1946 and 1977-78. Raw instrumental heights suggest a continued relative uplift to the north by about 3 or 4 cm between 1977 and 1984; however, these data could still be subject to systematic error.

Trilateration measurements were also carried out by the Geodetic Survey

on the central east coast of Vancouver Island. This survey work repeated earlier triangulation measurements in the area of Johnstone Strait (1918, 1966) and Forbidden Plateau (1978). The 1984 data are currently being reduced and analyzed and they may prove critical in resolving temporal and spatial variations in crustal strain in this active region.

As part of the NASA Crustal Dynamics Project, the first occupations of the Whitehorse and Penticton VLBI (Very Long Baseline Interferometry) sites by the NASA mobile radio antenna were completed in August 1984. These represent the first in a series of annual measurements planned over the next five years to monitor changes of the order of a few centimetres in baselines measuring thousands of kilometres. The Penticton site is being used in conjunction with the Yellowknife, N.W.T. and Algonquin, Ont. sites to monitor crustal deformation of the North American craton. The Whitehorse site serves as a reference location in the study of plate deformation in Alaska. The initial deployment of the mobile antenna at the remote sites of the Alaska campaign was carried out using a Hercules aircraft and thus presented a number of challenging logistics problems. (*Contact: H. Dragert.*)



NASA's mobile radio antenna system at the VLBI site adjacent to Whitehorse airport. By recording the radio signals from distant quasars simultaneously at a number of widely separated sites, it is possible to determine distances between these sites to a precision of a few centimetres.

Technical Support



Two technical services groups provide electronic and mechanical engineering support for the Pacific Geoscience Centre. The principal responsibility is the operation and maintenance of scientific and support equipment. Of increasing importance is the upgrading of existing equipment and the acquisition, preparation, maintenance and operation of new equipment.

A major advance in deep water capability was realized in 1984 with the purchase of a deep-tow winch with 8,000 metres of armoured co-axial cable. During the summer of 1984 this winch was used to carry out a wide swath, deep-tow side-scan survey of the offshore ridge system within Canada's 200 nautical mile economic zone. It is expected that any experiments which require power delivered to depth and/or data recorded on board in real time will make use of this system. This presents considerable opportunities to advance capabilities for high resolution side-scan surveys, real-time sea floor video, still photography of large areas and even perhaps the deployment of a deep water remotely operated vehicle.

(Contact: R. Macdonald.)

The use of mini- and micro-computers to control experiments and to log and process data is an area of extensive effort. Two IBM-PCs have been installed in the paleomagnetics laboratory to reduce Univac on-line time. In the sedimentology laboratory an IBM-PC is being installed to automate and integrate the sedigraph and settling table techniques. Sediment sorting and distribution parameters will be calculated once the whole sample size distribution has been derived. Cruise data acquisition and logging will now be carried out using an IBM-PC with GPIB interface. This will replace PHAS, a portable digital data acquisition system. At present, the new system accepts navigational, bathymetric and magnetic data. Development of a multi-channel digital seismic system based on a P.D.P. computer was continued. (Contact: W. Hill, I. Frydecky, G. Horel.)

An upgrading of side-scan sonar capabilities was realized with the purchase of K-MAPS. This system records survey parameters, corrects the data for scale changes due to variations in ship speed and then prints the data from a vertical rather than oblique perspective. Most ships in the research fleet (*Parizeau*, *Vector*, *Endeavour*) have been refitted to accept deep coring and long heat probe (11 metre) equipment. (Contact: W. Hill, R.D. Macdonald.)

An additional solar-powered seismic telemetry station was installed at Mt. Septimus on southern Vancouver Island.

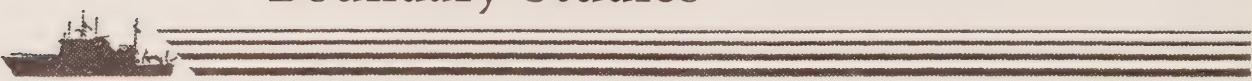
Offshore there was participation in a four-week cruise on *CNAV Endeavour* in June/July in support of the SeaMARC II mapping survey; seabed sediment heat flow measurements with a telemetering heat probe; and ocean-bottom geomagnetic measurements of both the earth's magnetic field and of generated fields, utilizing five successful deployments and recoveries of ocean bottom magnetometers. Technical support was also provided on a one-week cruise out of Seattle aboard the University of Oregon's Research Vessel *Wecoma* to deploy and recover the University of Toronto-designed MOSES system (ocean bottom transmitter and receiver) along the Endeavour segment of the Juan de Fuca Ridge. The deployment of the ocean bottom system from the support ship *Atlantis II* was followed by variation of the transmitter/receiver spacing via movement of the receiver package on the seafloor by the submersible *Alvin*.

Seafloor conductivity measurements were continued on two separate cruises to Bute and Toba Inlets, in conjunction with the University of Toronto, utilizing MOSES.

Initial planning and requisitions were completed for the addition of a VAX 11/750 to perform expanded data analysis on the seismic data acquired by the WCTN. Several additional IBM-PC micro-computers were also acquired. One of these was utilized for shipboard preliminary reduction, analysis and plotting of data from the telemetering heat probe. Preliminary efforts are underway to utilize an IBM-PC controller and analyzer for making shipboard measurements of thermal conductivity of core samples. (*Contact: M.N. Bone, H.J. Bennetts, H.A. Whitford.*)

Areas that are going to receive particular attention in the future are deep water photography, seismic (both deep penetration and shallow penetration-high resolution) and wire rope maintenance. (*Contact: I. Frydecky, R. Macdonald.*)

Boundary Studies



Between 1984 and 1987 PGC will generate a complete bibliographic

geoscience data base for the western Canada offshore international boundary areas in cooperation with the Atlantic Geoscience Centre, ISPG, Polar Continental Shelf Project and Earth Sciences, EMR, Ottawa and through a series of contracts and in-house studies. To date emphasis has been on regional data. In 1985 the focus will shift to detailed studies, resource appraisals plus data compilation and presentation as required by the Department of External Affairs for offshore boundary negotiations. The final output will be catalogues, data files and information summaries covering the boundary areas at Juan de Fuca, Dixon Entrance and the Beaufort Sea. (*Contact: J.B. Boyd.*)

APPENDIX I

Contracts Awarded 1984

A. Department of Fisheries and Oceans

<i>Develop a Computer Programming Training Course for IOS Personnel</i>		
Anthony Macauley Associates, Victoria, B.C.	\$ 7,475	
<i>Develop Software on IOS Image Processing System</i>		
Apocalypse Enterprises, North Saanich, B.C. .	19,000	
<i>Engineering Design of a Remote Liquid Crystal Display for Field Hydrography</i>		
Applied Microsystems Ltd., Sidney, B.C.	3,211	
<i>Develop a Conductivity, Salinity, Temperature, Depth and Water Velocity (CSTDV) System</i>		
Applied Microsystems Ltd., Sidney, B.C.	25,452	
<i>Develop and Construct a Microsystem Format Magnetic Tape Translator</i>		
Applied Microsystems Ltd., Sidney, B.C.	11,780	
<i>Compilation of Existing Chemical Oceanographic Data Sets for the Canadian West Coast Offshore Waters, Straits of Georgia and Juan de Fuca, Canada Basin and Arctic Ocean</i>		
Arctic Laboratories Ltd., Sidney, B.C.	19,445	
<i>Compilation of N.W. Passage Zoobenthos Data</i>		
Arctic Laboratories Ltd., Sidney, B.C.	48,049	
<i>Compilation and Appraisal of Existing Chemical Oceanographic Data from Queen Charlotte Sound, Hecate Strait and Dixon Entrance</i>		
Arctic Laboratories Ltd., Sidney, B.C.	25,982	
<i>Prepare and Test Acoustic Equipment and Recording Systems for the OERD Project to Determine Acoustic Scattering Parameters in Arctic Waters</i>		
Arctic Sciences Ltd., Sidney, B.C.	12,998	
<i>Compilation and Appraisal of Report for Physical Oceanography Data in Queen Charlotte Sound, Hecate Strait and Dixon Entrance</i>		
Arctic Sciences Ltd., Sidney, B.C.	34,565	
<i>Acoustic Scattering Measurements in Arctic Waters</i>		
Arctic Sciences Ltd., Sidney, B.C.	48,559	
<i>Development of a Digital Signal Processing Capability for the Extraction of Sea Ice Movement Data from Hard Copy Remote Sensing Imagery</i>		
Arctic Sciences Ltd., Sidney, B.C.	108,923	
<i>Acoustic Measurements of Flows in Channels</i>		
Arctic Sciences Ltd., Sidney, B.C.	81,008	
<i>Analysis of Active Sonar Schemes for Measuring Wind Direction</i>		
Arctic Sciences Ltd., Sidney, B.C.	33,439	
<i>Compilation and Appraisal of Existing Physical Oceanographic Data in the Canadian Basin of the Arctic Ocean</i>		
Arctic Sciences Ltd., Sidney, B.C.	18,020	
<i>Analysis of Arctic Acoustic Backscatter Data</i>		
Arctic Sciences Ltd., Sidney, B.C.	30,187	
<i>Investigate the Feasibility of Employed Gas Discharge Tube Technology for the Removal of Biofouling Rust, Paint, etc.</i>		
Associated Sheet Metal Products Ltd., Victoria, B.C.	28,570	
<i>Evaluation of Radiosonde Observations to Determine Optimum Methods of Computing Geostrophic Winds in Parry Channel</i>		
Atmospheric Dynamics Corp., Victoria, B.C. .	12,535	
<i>Enhancements to Hydrographic Contouring Software Package</i>		
Barrodale Computing Services Ltd., Victoria, B.C.	15,687	
<i>Investigation of Stereo-sidescan Sonar Imagery</i>		
Barrodale Computing Services Ltd., Victoria, B.C.	36,000	

<i>Provide Services of a Programmer/Analyst</i>	
Barrodale Computing Services Ltd., Victoria, B.C.	5,555
<i>Ship of Opportunity Sampling of the Planktonic Ecosystem off the Pacific Coast of Canada</i>	
Broccoli Bros. Enterprises Inc., Sidney, B.C.	14,176
<i>Analysis of Marine Zooplankton Samples</i>	
Broccoli Bros. Enterprises Inc., Sidney, B.C.	10,000
<i>Investigation of the Effects of the 1982/83 El Nino on Zooplankton Community Structure in B.C. Waters</i>	
Broccoli Bros. Enterprises Inc., Sidney, B.C.	88,120
<i>Evaluate an Ice Pressure Sensor, Inclusion Factor on Vertical Stress Distribution</i>	
Canada Marine Engineering Ltd., Calgary, Alberta	135,000
<i>Development of an Electrical Power Generator to Derive Useful Energy from Salinity Gradients through Application of Reserve Electro-dialysis Techniques</i>	
Capital Applied Research & Technology Ltd., Victoria, B.C.	77,688
<i>Multi-disciplinary Geophysical and Hydrographic Survey off Yukon Coast</i>	
Cansite Surveys Ltd., Calgary, Alberta	1,561,234
<i>Develop and Test a Structural Photo-voltaic Model for Marine and Survey Applications</i>	
Cantech Scientific Instruments Ltd., North Saanich, B.C.	67,013
<i>Study the Effects of Wood Waste for Ocean Disposal on Recruitment of Marine Benthic Communities (Macro Benthos)</i>	
Coastline Environmental Services, Vancouver, B.C.	7,492
<i>Study of Beam Characteristics and Sensitivity of Hydrophones and Transducers</i>	
G. Crawford, Victoria, B.C.	3,862
<i>Organisation of West Coast Ocean Dumping Workshop and Preparation of Workshop Proceedings for Publication</i>	
Dobrocky Seatech Ltd., North Saanich, B.C.	4,993
<i>Preparation of Report on Shelf Benthos Project</i>	
Dobrocky Seatech Ltd., North Saanich, B.C.	5,139
<i>Mobilisation of Sea Data System for Development in the North Pacific</i>	
Dobrocky Seatech Ltd., North Saanich, B.C.	12,747
<i>Develop, Construct and Field-test Loran C Tracked Drogues (Cont.)</i>	
Dobrocky Seatech Ltd., North Saanich, B.C.	5,273
<i>Organisation of Workshop on Metal Binding Proteins Produced by Non-Mammalian Organisms in Aquatic Environments</i>	
Dobrocky Seatech Ltd., North Saanich, B.C.	21,500
<i>Develop and Test a Deep Ocean Interstitial Water Sampling Device</i>	
Dobrocky Seatech Ltd., North Saanich, B.C.	100,000
<i>Identify and Enumerate Marine Phytoplankton from Station P</i>	
E.V.S. Consultants Ltd., Sidney, B.C.	4,422
<i>Compile, Review and Assess Major Environmental Assessment Reports and Atlases for West Coast of British Columbia</i>	
Environmental Services Ltd., Vancouver, B.C.	12,550
<i>A Fibre Optic Implementation of a Remote Sensing Head to Measure In-situ Phytoplankton Fluorescence</i>	
Focal Marine, Halifax, Nova Scotia	80,000
<i>Collection and Compilation of Oceanographic Data in the Campbell River Estuary</i>	
A. Hartley, Vancouver, B.C.	3,900
<i>Documentation of Specific Oceanographic Data Relating to Various Arctic and Pacific Coastal Areas</i>	
R. Herlinveaux, North Saanich, B.C.	10,575
<i>Test and Analyse Echometer Instrument</i>	
D. Huston, Victoria, B.C.	5,100
<i>Test and Analyse Echometer Instrument</i>	
D. Huston, Victoria, B.C.	4,000
<i>Reduction of STEDPO to One Sounder</i>	
Interact Computing Services Ltd., Sidney, B.C.	8,458
<i>Processing of Current Meter Data Obtained During Stage II of the North Coast Oceanic Dynamics Experiment</i>	
Interact Computing Services Ltd., Sidney, B.C.	4,882

<i>Investigation of a Novel Approach to the Problem of Double Diffusive Instability</i>	
Interact Computing Services Ltd., Sidney, B.C.	153,117
<i>Preparation of Microfiche Tape for Technical Support in Line P Deep Ocean Time Series Analysis</i>	
Interact Computing Services Ltd., Sidney, B.C.	8,528
<i>Develop Additional Range Bearing Functions to HAL/HALPRO Software</i>	
Interact Computing Services Ltd., Sidney, B.C.	7,452
<i>Study of North Pacific Transient and Stationary Heat Fluxes</i>	
Interact Computing Services Ltd., Sidney, B.C.	3,787
<i>Measurements of Hydrographic Launch Dynamics</i>	
Interact Computing Services Ltd., Sidney, B.C.	19,968
<i>Software Package</i>	
Interfax Systems Inc., Burnaby, B.C.	15,274
<i>Design of Free Floating Multi-sediment Trip Array</i>	
Iseki, Saanichton, B.C.	22,520
<i>Collection and Analysis of Samples from Moored Sediment Trap and Surface Water Samples in the Pacific</i>	
ISK, Saanichton, B.C.	16,165
<i>Preliminary Study to Determine Various Aspects of Undersea Acoustic Techniques to Determine Rainfall</i>	
Jasco Research Ltd., North Saanich, B.C.	1,250
<i>Development of an Undersea Acoustic Technique to Determine Rainfall</i>	
Jasco Research Ltd., North Saanich, B.C.	162,600
<i>Design and Development of an Oceanographic Mooring System off the West Coast of Queen Charlotte Islands</i>	
T. Juhasz, Victoria, B.C.	68,300
<i>Study of Growth Decay of Crystals in Seawater</i>	
D.G. Knigge-Sieberg, Victoria, B.C.	15,960
<i>Compilation of Tsunami Records</i>	
M. Lane, Victoria, B.C.	621
<i>Study of Antenna Configurations for the Active Drifter</i>	
Meteor Communications (Canada) Corp., Victoria, B.C.	1,909
<i>Technical Modification, Maintenance and Test Flight of the Fluorescence Line Imager (FLI)</i>	
Moniteq, Concord, Ontario	27,802
<i>Continuation of Technical Improvements and Evaluation of FLI</i>	
Moniteq, Concord, Ontario	82,147
<i>Survey of Acoustic Profiling of an Arctic Ice Keel</i>	
Offshore Survey and Navigation Ltd., North Vancouver, B.C.	31,640
<i>Develop a Microcomputer-based Tidal Current Display System</i>	
Pacific Ocean Sciences Ltd., Burnaby, B.C.	84,000
<i>Study of Numerical Prediction of Wind Generated Waves in the Coastal Area between Queen Charlotte Islands and the Mainland of British Columbia</i>	
Pacific Ocean Sciences Ltd., Burnaby, B.C.	124,000
<i>Survey of Practical Data Analysis Techniques used in Physical Oceanography</i>	
Pacific Ocean Sciences Ltd., Burnaby, B.C.	6,000
<i>Graphical Presentation and Analysis of Oceanographic Data</i>	
Pacific Ocean Sciences Ltd., Burnaby, B.C.	9,285
<i>Data Interception of Ships of Opportunity</i>	
Pacific Ocean Sciences Ltd., Burnaby, B.C.	1,100
<i>Analysis of Marine Tissue Digests by Inductively Coupled Plasma Spectrometry</i>	
Quanta Trace Labs Inc., Burnaby, B.C.	3,519
<i>Study of a Marine Boundary Layer Structure and Heat Exchange</i>	
S & B Research Ltd., Saanichton, B.C.	6,933
<i>Design for a Thruster for the Active Drifter</i>	
Seaboy Marine Services Ltd., Sidney, B.C.	5,000
<i>Study to Develop a Search & Rescue (SAR) Procedure for Hazardous Waters</i>	
Seaconsult Marine Research Ltd., Vancouver, B.C.	160,000
<i>Demonstration of SEA-I Research Sidescan Sonar and Manta Underwater Vehicle</i>	
SEA-I Research Ltd., Sidney, B.C.	2,500
<i>Organisation of West Coast Ocean Dumping Workshop and Preparation of Workshop Proceedings for Publication</i>	
SEA-I Research Ltd., Sidney, B.C.	4,990

<i>Development of a Novel Model Using the Edible Mussel as a Sentinel Organism for Monitoring Organic Contamination of the Marine Environment</i>	Sytech Research Ltd., Sidney, B.C.	3,960
<i>Seakem Oceanography Ltd., Sidney, B.C. 7,000</i>		
<i>Investigation of a Novel Laser Diode Pressure Sensor</i>	Sytech Research Ltd., Sidney, B.C.	2,650
<i>Seakem Oceanography Ltd., Sidney, B.C. 238,000</i>		
<i>Analysis of Marine Air Samples from Land Station & Ocean Cruises</i>	I. Szabo, North Saanich, B.C.	2,550
<i>Seakem Oceanography Ltd., Sidney, B.C. 40,000</i>		
<i>Study of Natural and Petroleum Exploration-related Fluxes of Metals, Hydrocarbons and Nutrients in Queen Charlotte Sound</i>	Terra Surveys Ltd., Sidney, B.C.	58,239
<i>Seakem Oceanography Ltd., Sidney, B.C. 9,483</i>		
<i>Analysis of Dissolved Nutrients in Seawater and Artificial Seawater</i>	Terra Surveys Ltd., Sidney, B.C.	14,406
<i>Seakem Oceanography Ltd., Sidney, B.C. 6,200</i>		
<i>Analysis of Seawater and Sediment Trap Samples for Dissolved Nutrients</i>	C. Parizeau, North Saanich, B.C.	52,520
<i>Seakem Oceanography Ltd., Sidney, B.C. 6,000</i>		
<i>Compilation of Summary Statistics from West Coast Ship of Opportunity Data</i>	Tide and Tsunami Services, Saltspring Island, B.C.	27,216
<i>Seakem Oceanography Ltd., Sidney, B.C. 9,848</i>		
<i>Feasibility Study for the Development of a Fast Response Fibre Optic Dissolved Oxygen Sensor</i>	Univ. of Victoria, Dept. of Physics, Victoria, B.C.	2,000
<i>Seastar Instruments Ltd., Sidney, B.C. 11,677</i>		
<i>Determination of Modifications Required for High Frequency Operation of IOS Upward-looking Sonar Array</i>	Univ. of Victoria, Dept. of Chemistry, Victoria, B.C.	8,455
<i>SH Scientific Computing Ltd., Vancouver, B.C. 4,495</i>		
<i>Modifications & Additions to Turbidostat Hardware and Software</i>	Univ. of Washington, Dept. of Applied Physics, Seattle, U.S.A.	7,184
<i>SH Scientific Computing Ltd., Vancouver, B.C. 1,650</i>		
<i>Development of CADD based Technology for the Production of Maps of Ocean Bathymetry</i>	Univ. of Washington, Polar Science Centre, Applied Physics Laboratory, Seattle, U.S.A.	11,880
<i>H.A. Simons International Ltd., Vancouver, B.C. 81,000</i>		
<i>Library Cataloguing of Tsunami</i>	Western Ecological Service (B.C.) Ltd., North Saanich, B.C.	16,180
<i>P. Straub, Sidney, B.C. 605</i>		

<i>Development of Data, Software and Documentation for Launch Computed Line Following System</i>	Western Subsea Technology, Sidney, B.C.	10,375
<i>New Charting Scheming of Mackenzie River, N.W.T.</i>	R. Wills, Victoria, B.C.	20,450
B. Department of Energy, Mines and Resources		
<i>Data Compilation and Laboratory Analysis of Sediments for Investigation of Geohazards to Development on the Continental Shelf off Western Canada</i>	K. Conway, Victoria, B.C.	25,448
<i>Marine Survey of Nearshore Sedimentation and Recent Tectonics of Virago Sound, Northern Graham Island</i>	Offshore Survey and Positioning Services Ltd., Vancouver, B.C.	35,000
<i>Development and Testing of a Deep Ocean Interstitial Water Sampling Device</i>	Dobrocky Seatech Ltd., North Saanich, B.C. .	119,204
<i>Collection of Oceanographic Data using Huntec Deevent Seismic System</i>	Huntec (70) Ltd., Vancouver, B.C.	23,996
<i>Compilation of Western Canadian Telemetered Network Seismogram Collection</i>	R. Kolinsky, Sidney, B.C.	12,000
<i>Compilation of Western Canadian Telemetered Network Seismogram Collection</i>	P. Wilkman, Victoria, B.C.	12,600
<i>Investigation and Installation of Seismic Station in Queen Charlotte Island Areas</i>	B. Chandra & Associates Ltd., Vancouver, B.C.	5,000
<i>Seismographic Data Collection at Selected Sites on the West Coast of British Columbia</i>	Univ. of British Columbia, Vancouver, B.C. . .	10,450
<i>Study of Upper Crustal Structure below Hecate Strait from Airguns Ocean Bottom Seismograph Data</i>	Univ. of British Columbia, Vancouver, B.C. . .	14,727
<i>Study of Crustal Structure of Queen Charlotte Islands—Hecate Strait Region—from Seismic Refraction Studies</i>	Univ. of British Columbia, Vancouver, B.C. . .	14,493
<i>Analysis of Micro-earthquake Data form the Queen Charlotte Islands and Hecate Strait Region</i>	Univ. of British Columbia, Vancouver, B.C. . .	15,000
<i>Investigation of the Earthquakes West of Vancouver Island</i>	Univ. of British Columbia, Vancouver, B.C. . .	20,243
<i>Seismic Monitoring of the Anahim Volcanic Belt in Eastern British Columbia</i>	B. Chandra & Associates Ltd., Vancouver, B.C.	56,000
<i>Preparation of Tailored Bibliographics in the Juan de Fuca International Boundary Area</i>	Envirocon Ltd., Vancouver, B.C.	15,000

APPENDIX II

Publications

A. Department of Fisheries and Oceans

(1) Canadian Data Report of Hydrography and Ocean Sciences

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| No. 5
Volume 7 | Birch, J.R., D.B.
Fissel, A.B. Cornford
and H. Melling | <i>Arctic Data Compilation and Appraisal. Canadian Basin-Arctic Ocean: Physical Oceanography – Temperature, Salinity, Current and Water Levels</i> |
| No. 17
Parts I, II, III | Macdonald, R.W.,
M.C. O'Brien and
D.M. Macdonald | <i>Ocean Chemistry Data Report: Alice Arm, Observatory Inlet</i> |
| No. 23
Vols. 1, 2, 3 | Thomson, R.E., W.R.
Crawford and
W.S. Huggett | <i>Water property observations off the west coast of Vancouver Island during CODE: May 1979 to September 1980</i> |
| No. 25 | Giovando, L.F. | <i>Observations of seawater temperature and salinity of British Columbia shore stations, 1982</i> |

(2) Canadian Technical Report of Hydrography and Ocean Sciences

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| No. 33 | Macdonald, R.W. and
H. Nelson | <i>A laboratory performance check for the determination of metals (Hg, Zn, Cd, Cu, Pb) in reference marine sediments</i> |
| No. 34 | Woppard, A.L. | <i>The selection of tidal boundary condition for a numerical river model</i> |
| No. 37 | Brinkhurst, R.O.
R.O. Kathman, R.E.
Woods and S.F. Cross | <i>Benthic studies in Alice Arm, B.C. following cessation of mine tailings disposal</i> |
| No. 38 | Juniper, S.K. and
R.O. Brinkhurst (eds.) | <i>Proceedings of a multidisciplinary symposium on Saanich Inlet, February 2, 1983</i> |
| No. 44 | Brinkhurst, R.O. and
M.J. Wetzel | <i>Aquatic oligochaeta of the world: supplement – a catalogue of new freshwater species, descriptions and revisions</i> |
| No. 52 | Vermeer, K. and
L. Rankin | <i>Pelagic seabird populations in Hecate Strait and Queen Charlotte Sound: comparison with the west coast of the Queen Charlotte Islands</i> |

(3) Canadian Contract Report of Hydrography and Ocean Sciences

No. 17	S.M. Woods (ed.)	<i>Report on Ocean Dumping R&D Pacific Region, Department of Fisheries and Ocean, 1982-83</i>
No. 15	Fissel, D.B., D.N. Knight and J.R. Birch	<i>An oceanographic survey of the Canadian Arctic archipelago March 1982</i>
No. 16	Fissel, D.B., D.D. Lemon and D.N. Knight	<i>An oceanographic survey of the Canadian Arctic archipelago March 1983</i>

(4) Other Publications

- ABBOTT, M.R., K.L. DENMAN, T.M. POWELL, P.J. RICHERSON, R.C. RICHARDS and C.R. GOLDMAN. 1984. Mixing and the dynamics of the deep chlorophyll maximum in Lake Tahoe. *Limnology and Oceanography*, **29**: 862-878.
- BAKER, H.R. 1984. Diversity and zoogeography of marine Tubificidae (Annelida, Oligochaeta) with notes on variation in widespread species. In: *Proceedings of the Second Aquatic Oligochaete Symposium*, C. Erseus and G. Bonomi (eds.), Hydrobiologia, **115**: 191-196.
- BARBER, F.G., J.D. TAYLOR, P.A. BOLDUC and T.S. MURTY. 1984. Influence of ice cover on resonance phenomenon in Tuktoyaktuk harbour. In: *Proceedings of Symposium on Science and Arctic Hydrocarbon Exploration*, Dept. Economic Development, Whitehorse, Yukon, 302-326.
- BENNETT, A.F. 1984. Relative dispersion: local and non-local dynamics. *Journal of the Atmospheric Sciences*, **41**, 1881-1886.
- BLUETT, B. and R.W. MACDONALD. 1984. Sampling for suspended particulate matter, trace metal and hydrocarbon inputs to the Beaufort Sea. *Ocean Chemistry Project Report*, **37** pp.
- BOLTON, M. 1984. Hydrography – make or buy? In: *Papers, The Second International Hydrographic Conference*, Paper 13, September 1984.
- BORSTAD, G.A. and J.F.R. GOWER. 1984. Phytoplankton chlorophyll distribution in the eastern Canadian Arctic. *Arctic*, **37**, December 1984.
- BRINKHURST, R.O. 1984. Two new species of Tubificidae (Oligochaeta) from the northern territory of Australia. In: *Proceedings of the Biological Society of Washington*, **97**: 142-147.
- BRINKHURST, R.O. 1984. A revision of the Tubificidae and Lycodrilidae (Annelida, Oligochaeta) known from Lake Baikal. *Canadian Journal of Zoology*, **62**: 494-509.

- BRINKHURST, R.O. 1984. Comments on the evolution of the Annelida. *Hydrobiologia*, **109**: 189-191.
- BRINKHURST, R.O. and R.D. KATHMAN. 1984. Some benthic invertebrates from Tennessee and Kentucky caves. *Journal of the Tennessee Academy of Science*, **59**: 19-21.
- BRINKHURST, R.O. 1984. The position of the Haplotaxidae in the evolution of the annelids. In: *Proceedings of the Second Aquatic Oligochaete Symposium*, C. Erseus and G. Bonomi (eds.), *Hydrobiologia*, **115**: 25-36.
- BROWN, E.H., D.M. FARMER, J.J. GILHEANY and W.E. WOODWARD. 1984. The echometer: an acoustic sound speed profiler. *IEEE Trans. on Geosc. and Rem. Sens.*, **GE-22**: 641-647.
- BURD, B. and R.O. BRINKHURST. 1984. The distribution of the Galatheid crab *Munida quadrispina* (Benedict 1902) in relation to oxygen concentrations in British Columbia fjords. *Journal of Experimental Marine Biology and Ecology*, **81**: 1-20.
- CHAPMAN, P.M. and R.O. BRINKHURST. 1984. Lethal and sublethal tolerances in aquatic oligochaetes with reference to their use as a biotic index of pollution. In: *Proceedings of the Second Aquatic Oligochaete Symposium*, C. Erseus and G. Bonomi (eds.), *Hydrobiologia*, **115**: 139-144.
- DENMAN, K.L. and T.M. POWELL. 1984. Effects of physical processes on planktonic ecosystems in the coastal ocean. *Oceanography and Marine Biology: An Annual Review*, **22**: 125-168.
- EL-SABH, M.I., T.S. MURTY and J.M. BRIAND. 1984. Les ondes de tempête dans l'estuaire du Saint-Laurent. *Sciences et Techniques de L'Eau*, **17**(1): 15-22.
- FARMER, D.M. and D.D. LEMON. 1984. The influence of bubbles on ambient noise in the ocean at high wind speeds. *J. Phys. Oc.*, **14**: 1761-1777.
- FILLMORE, S. and R.W. SANDILANDS. 1984. *L'hydrographie au Canada*. NC Press, Toronto, Canada, 254 pp.
- FOREMAN, M.G.G. 1984. A two dimensional analysis of the wave equation model for finite element tidal computations. In: *Finite Elements in Water Resources, Proceedings of the Fifth International Conference*, Burlington, Vermont, June 1984, J.P. Laible et al (eds.), Springer-Verlag, Berlin, 447-456.
- FOREMAN, M.G.G. 1984. A two dimensional dispersion analysis of selected methods for solving the linearized shallow water equations. *Journal of Computational Physics*, **56**(2): 287-323.
- FOREMAN, M.G.G. 1984. *Dispersion Analyses of Finite Element Solutions of the Shallow Water Equations*, Ph.D. thesis, Dept. of Mathematics, University of British Columbia, 199 pp.
- FREELAND, H.J. and L.F. GIOVANDO. 1984. The 1982-83 Pacific warm event off British Columbia. *Trop. Ocean-Atmos. Newsletter*, **23**: 18-19.
- FREELAND, H.J., W.R. CRAWFORD and R.E. THOMSON. 1984. Currents along the Pacific coast of Canada. *Atmosphere-Ocean*, **22**(2): 151-172.

- FREELAND, H.J. 1984. The partition of internal tidal motions in Knight Inlet, British Columbia. *Atmosphere-Ocean*, **22**(2): 144-150.
- GALLOWAY, J.L. 1984. Applications of S.A.I.L. systems at I.O.S. In: *1983 IEEE Proceedings of the Third Working Symposium on Oceanographic Data Systems*.
- GALLOWAY, J.L. and J.S. COLLINS. 1984. Acoustic telemetry of video information. In: *Proceedings, Ocean's 83 IEEE*.
- GALLOWAY, J.L. 1984. SeaMARC II: A Hydrographic Evaluation. *I.O.S. Report*.
- GARGETT, A.E. 1984. Vertical eddy diffusivity in the ocean interior. *J. Mar. Res.*, **42**: 359-393.
- GARGETT, A.E., T.R. OSBORN and P.W. NAYSMITH. 1984. Local isotropy and the decay of turbulence in a stratified fluid. *J. Fluid Mech.*, **144**: 231-280.
- GARGETT, A.E. 1984. Internal waves and mixing in the ocean: observations and speculations. In: *Proceedings of the Second 'Aha Haliko' a Hawaiian Winter Workshop*, P. Muller (ed.), Dept. Oceanography, University of Hawaii.
- GARGETT, A.E. and G. HOLLOWAY, 1984. Dissipation and diffusion by internal wave breaking. *Journal of Marine Research*, **42**: 15-27.
- GOWER, J.F.R., S. LIN and G.A. BORSTAD. 1984. The information content of different optical spectral ranges for remote chlorophyll estimation in coastal waters. *Int. J. Remote Sensing*, **5**: 349-364.
- GOWER, J.F.R. 1984. Water colour imaging from space. In: *Remote Sensing of Shelf Sea Hydrodynamics*, C.J.C. Nihoul (ed.), Elsevier, 1-24.
- GOWER, J.F.R., G.A. BORSTAD and D. TRUAX. 1984. The use of ocean colour data to map surface dynamic features. *Paper presented at the Eighteenth Annual Congress of the Canadian Meteorological and Oceanographic Society*, Dalhousie University, Halifax, Nova Scotia, May 29-June 1.
- GOWER, J.F.R. 1984. Mapping ocean dynamic structure using optical spectroscopic measurements from space. *Paper presented at the Twenty-fifth Plenary Meeting of Cospar, Symposium No. 4, Space Observations for Climate Studies*, Graz, Austria, June 25-29.
- GOWER, J.F.R. 1984. Optical imaging of the sea surface with high spectral resolution. *Paper presented at the Ninth Canadian Symposium on Remote Sensing*, Memorial University, St. John's, Newfoundland, August 13-17.
- GRAY, M., M. DANARD, R. FLATHER, R.F. HENRY, T.S. MURTY, S. VENKATESH and C. JARVIS. 1984. A preliminary investigation using a Nova Scotia storm surge prediction model. *Atmosphere-Ocean*, **22**(2): 207-225.

- HOLLOWAY, G. and S.S. KRISTMANNSSON. 1984. Stirring and transport of tracer fields by geostrophic turbulence. *Journal of Fluid mechanics*, **141**: 27-50.
- HOLLOWAY, G. 1984. Effects of velocity fluctuations on vertical distributions of phytoplankton. *Journal of Marine Research*, **42**: 559-571.
- HOLLOWAY, G. 1984. Probing the internal wave strong interaction regime by numerical experimentation. In: *Proceedings of the Second Hawaiian Winter Workshop*, University of Hawaii, 1984, 221-248.
- ISEKI, K., R.W. MACDONALD AND C.S. WONG. 1984. Effect of wood waste dumping on organic matter in sea water and surficial sediments of Alberni Inlet, British Columbia. *J. Oceanogr. Soc. Japan*, **40**: 213-220.
- LEMON, D.D., D.M. FARMER and D.R. WATTS. 1984. Acoustic measurements of wind speed and precipitation over a continental shelf. *Journal of Geophysical Research*, **89(C3)**: 3462-3472.
- LEWIS, E.L. 1984. Optimal design of CTD sensor heads for salinity determination. STD 1984 Conference Workshop, San Diego Section, Marine Technology Society, 23-27.
- LIN, S., G.A. BORSTAD and J.F.R. GOWER. 1984. Remote sensing of chlorophyll in the red spectral region. In: *Remote Sensing of Shelf Sea Hydrodynamics*, C.J.C. Nihoul (ed.), Elsevier, 317-336.
- MACDONALD, R.W. 1984. Guidelines for obtaining, calculating and reporting quality statements for chemical analysis of marine sediments. *Unpublished manuscript*, 91 pp.
- MACKAS, D.L. 1984. Spatial autocorrelation of plankton community composition in a continental shelf ecosystem. *Limnology and Oceanography*, **29**: 451-471.
- MACKAS, D.L. 1984. Book review of Mathematical Models in Biological Oceanography. *Atmosphere-Ocean*, **22**: 123-124.
- MACKAS, D.L. 1984. Studying the basics of life. *Sounder*, **12**: 13-14.
- MCINTOSH, P.C. and A.F. BENNETT. 1984. Open ocean modelling as an inverse problem: M₂ tides in Bass Strait. *Journal of Physical Oceanography*, **14**: 601-614.
- MELLING, H., R.A. LAKE, D.R. TOPHAM and D.B. FISSEL. 1984. Oceanic thermal structure in the western Canadian Arctic. *Cont. Shelf Res.*, **3**: 233-258.
- MIYAKE, M., G.A. BORSTAD and J.F.R. GOWER. 1984. Freshwater-driven eastern boundary current in the Pacific. *Paper presented at the Eighteenth Annual Congress of the Canadian Meteorological and Oceanographic Society*, Dalhousie University, Halifax, Nova Scotia, May 29-June 1.
- MURTY, T.S. 1984. *Storm Surges—Meteorological Ocean Tides*. Bull. 212, Canadian Journal of Fisheries and Aquatic Sciences, Ottawa, 897 pp.

- MURTY, T.S. 1984. Diffusive kinematic waves versus hyperbolic long waves in tsunami propagation. In: *Proceedings of IUGG Tsunami Symposium*, E.N. Bernard (ed.), Hamburg, August 1983, 1-21.
- MURTY, T.S. and H.G. LOOMIS. 1984. Diffracted long waves along continental shelf edges. In: *Proceedings of IUGG Tsunami Symposium*, E.N. Bernard (ed.), Hamburg, August 1983, 211-228.
- MURTY, T.S. and M.I. EL-SABH. 1984. Cyclones and storm surges in the Arabian Sea: a brief review. *Deep Sea Research*, **31**: 665-670.
- MURTY, T.S. 1984. Realistic assessment of maximum flood potentials. *J. of Hydraulic Engineering*, **110**(8): 1174-1175.
- MURTY, T.S. and M.I. EL-SABH. 1984. Storm tracks, storm surges and sea state in the Arabian Gulf, Strait of Hormuz and the Gulf of Oman, oceanographic modelling of the Kuwait action plan region. *UNESCO Reports in Marine Sciences*, no. 28, M.I. El-Sabah (ed.), 12-24.
- MURTY, T.S., M.I. EL-SABH and Y. GRATTON. 1984. Hurst phenomenon in tsunami-genic earthquake data. *Science of Tsunami Hazards*, **2**(1): 55-63.
- MURTY, T.S. and M.I. EL-SABH. 1984. Comments on shapes of streamlined islands on Earth and Mars. Experiments and Analyses of the Minimum Drag Form. *Geology*, **12**(9): 569-570.
- MURTY, T.S. and W. RAPATZ. 1984. The largest tides on the globe. *Boating Magazine*, June 1984, 38-39.
- MURTY, T.S. 1984. Tsunami Detection Systems for the Pacific Ocean. *Proceedings of the Pacific Congress on Marine Technology*, Honolulu, April 24-27, 1984, 5 pp.
- MURTY, T.S. and M.I. EL-SABH. 1984. A universal Strauhal law. *Journal of Engineering Mechanics*, American Soc. of Civil Engineers, **110**(5): 839-841.
- NEMEC, A.F.L. 1984. Conditionally heteroscedastic autoregressions. *Technical Report*, 43. Department of Statistics, University of Washington, 26 pp.
- NEMEC, A.F.L. 1984. Least squares estimation of conditionally heteroscedastic autoregressions. *Technical Report*, 48, Department of Statistics, University of Washington, 18 pp.
- PERKIN, R.G. and E.L. LEWIS. 1984. Mixing in the west Spitsbergen current. *J. Phys. Oc.*, **14**(8).
- SEKI, H., T. SAIDO, K. ISEKI, F.A. WHITNEY and C.S. WONG. 1984. Uptake kinetics of micro-organisms in the sulfetum of Saanich Inlet. *Arch. Hydrobiol.*, **100**: 73-81.
- SMITH, G.R. 1984. The Active Drifter, an autonomous data buoy. In: *Proceedings of the Pacific Congress on Marine Technology*, (PACON '84), Marine Technology Society.

- TABATA, S. 1984. Accuracy of NOAA-7 observed SST in the northeast Pacific Ocean. *Satellite-derived sea surface temperature: Workshop II*, June 22-24, Pasadena, California, NASA, JPL, California Institute of Technology, 145 pp., 10-18.
- TABATA, S. 1984. Oceanographic conditions off the Pacific coast of Canada during the 1982-1983 El Nino. In: *Proceedings of the Eight Annual Climate Diagnostics Workshop*, U.S. Dept. Commerce, NOAA, 401 pp., 92-99.
- TABATA, S. 1984. Anomalously warm water off the Pacific coast of Canada during the 1982-1983 El Nino. *Trop. Ocean-Atmos. Newsletter*, **24**: 7-9.
- TABATA, S. 1984. Oceanographic factors influencing the distribution, migration and survival of salmonids in the northeast Pacific Ocean – A review. In: *The Influence of Ocean Conditions on the Production of Salmonids in the North Pacific*, W.G. Pearcy (ed.), Oregon State University Sea Grant College Program, ORESU-W-83-001, 327 pp., 128-160.
- THOMPSON, J.A.J. and R.P. COSSON. 1984. An improved electrochemical method for the quantification of metallothioneins in marine organisms. *Marine Environmental Research*, **11**: 137-152.
- THOMSON, R.E., H.J. FREELAND and L.F. GIOVANDO. 1984. Long term sea-surface temperature variations along the British Columbia coast. *Trop. Ocean-Atmos. Newsletter*, **26**: 9-11.
- TOPHAM, D.R. and R.G. PERKIN. 1984. On the transient behaviour of conductivity sensors. *Journal of Atmospheric and Oceanic Technology*, September 1984, Vol. 1, No. 3.
- TOPHAM, D.R. 1984. The formation of gas hydrate bubbles of hydrocarbon gases rising in seawater. *Chemical Engineering Science*, **39**(5): 821-828.
- TOPHAM, D.R. 1984. The modelling of hydrocarbon bubble plumes to include gas hydrate formation. *Chemical Engineering Science*, **39**(11): 1613-1622.
- TOPHAM, D.R., P.R. CLEMENTS and P.R. SMY. 1984. Turbulent mixing in a pulsed plasma jet exhaust. *Journal of Fluid Mechanics*, November 1984, Vol. 147: 207-224.
- TUNNICLIFFE, V., K. JUNIPER and M. DE BURGH. 1984. Biological communities of the Juan de Fuca hydrothermal vents. *Bulletin of the Biological Society of Washington*, **7**: 000-000.
- YAO, T., H.J. FREELAND and L.A. MYSAK. 1984. A comparison of low frequency current observations off B.C. with coastal trapped wave theory. *Journal of Physical Oceanography*, **14**(1): 22-34.
- WIGEN, S.O., T.S. MURTY and D.G. PHILIP. 1984. Tsunami of May 11, 1981 on the coast of South Africa. In: *Proceedings of IUGG Tsunami Symposium*, E.N. Bernard (ed.), Hamburg, August 1983, 187-202.
- WONG, C.S. Y.-H. CHAN, J.S. PAGE, R.D. BELLEGAY and K.G. PETTIT. 1984. Trends of atmospheric CO₂ over Canadian WMO background stations at ocean weather station P, Sable Island and Alert. *J. Geophys. Res.*, **89**: 9527-9539.

- WONG, C.S., F.A. WHITNEY, W.J. CRETNEY, K. LEE, F. MCLAUGHLIN, JINPING WU, TIANBOA FU and DONGFA ZHUANG. 1984. An experimental marine ecosystem response to crude oil and Corexit 9527: Part 1 – fate of chemically dispersed crude oil. *Marine Environmental Research*, **13**: 1-17.
- WONG, C.S., F.A. WHITNEY, W.K. JOHNSON, T.R. PARSONS, P.J. HARRISON, C.M. LALLI, P. THOMPSON, WU YUNG, J. ACREMAN, HOU SHUMIN, WU JINPING, WU SHENG SAN, LU XIAKUN, XU HUAI-SHU and LI JINXIA. 1984. The addition of Amax mine tailings to controlled experimental ecosystems. *Marine Ecosystem Enclosure Experiment Data Report*, 84-1, 42 pp.
- WONG, C.S., C.D. KEELING, P.G. BREWER, G. CRESSWELL, Y. HORIBE, G. LAMBERT, K.O. MUNNICH, A. POISSON, A. CHEN, G. CHAN, Y. DANDONNEAU, R. FEELY, R. GAMMON, J. KELLEY AND Z. MA. 1984. Oceanic CO₂ Measurements, *Report of SCOR Working Group 75*, Lake Arrowhead, California, May 1984, 21 pp.
- WONG, C.S. and S. HONJO. 1984. Material flux at ocean weather station P, high-frequency time-series observations through production cycles. *Invited paper at Pelagic Sedimentation Geology and Geochemistry session, AGU meeting*, Cincinnati, May 14-17, 1984, *EOS*, **65**: 225 (abstract).
- WONG, C.S., K. ISEKI and S. HONJO. 1984. Seasonality of particulate flux at ocean station P. Abstract in: *Proceedings of Forty-Seventh Annual Meeting of the American Society of Limnology and Oceanography*, June 11-14, 1984, Vancouver, B.C.

B. Department of Environment

- MCKEAN, G.A. et al. 1984. Report of WMO-CAS expert meeting on atmospheric boundary-layer parameterization over the oceans for long-range forecasting and climate models. *WMO-WCP Report 74*, 112 pp.
- MCKEAN, G.A. 1984. Storm sections from mobile-ship upper-air observations. *Pac. Reg. AES Tech. Note 84-004*, 9 pp.
- UNTERSTEINER, N., G.A. MCKEAN et al. 1984. Report of WMO-JSC expert meeting on sea ice and climate modelling. *WMO-WCP Report 77*, 232 pp.
- VERMEER, K. and J.S. WESTRHEIM. 1984. Fish changes in the Rhinoceros Auklet diet and their implications. In: *Marine Birds: Their Feeding Ecology and Commercial Fisheries, Proceedings of the Pacific Seabird Group Symposium*, Seattle, Washington, January 6-8, 1982, D.N. Nettleship, G. Sanger and P.J. Springer (eds.), Can. Wildlife Service Special Publication, Ottawa, 90-105.
- VERMEER, K. and N. BOURNE. 1984. The White-winged Scoter diet in British Columbia waters: resource partitioning with other scoters. In: *Marine Birds: Their Feeding Ecology and Commercial Fisheries, Proceedings of the Pacific Seabird Group Symposium*, Seattle,

Washington, January 6-8, 1982, D.N. Nettleship, G. Sanger and P.J. Springer (eds.), Can. Wildlife Service Spec. Publ., Ottawa, 30-38.

VERMEER, K. and L. RANKIN. 1984. Population trends in nesting Double-crested and pelagic Cormorants in Canada. *Murrelet*, **65**: 1-9.

VERMEER, K. and L. RANKIN. 1984. Influence of habitat destruction and disturbance on nesting seabirds. In: *Status and Conservation of the World's Seabirds*, J.P. Croxall, P. Evans and R.W. Schreiber (eds.), ICBP Tech. Bull., No. 2, Cambridge, England.

VERMEER, K. and S.G. SEALY. 1984. Status of the nesting seabirds of British Columbia. In: *Status and Conservation of the World's Seabirds*, J.P. Croxall, P. Evans and R.W. Schreiber (eds.), ICBP Tech. Bull., No. 2, Cambridge, England.

VERMEER, K., S.G. SEALY, M. LEMON and M. RODWAY. 1984. Predation and potential environmental perturbances of Ancient Murrelets nesting in British Columbia. In: *Status and Conservation of the World's Seabirds*, J.P. Croxall, P. Evans and R.W. Schreiber (eds.), ICBP Tech. Bull. No. 2, Cambridge, England.

VERMEER, K. 1984. The diet and food consumption of nestling Cassin's Auklets during summer, and a comparison with other plankton-feeding alcids. *Murrelet*, **65**: 65-77.

C. Department of Energy, Mines and Resources

BENTKOWSKI, W.H. and T.J. LEWIS. 1984. Preliminary results from shallow drilling in the Alert Bay volcanic belt, 1982. *Earth Physics Branch Open File Report 84-2*, 16 pp.

BECKER, K., M.S. LANGSETH and R.D. HYNDMAN. 1984. Temperature measurements in hole 395A, Leg 78B. In: *Initial Reports of the Deep Sea Drilling Project, 78B*, R.D. Hyndman, M.H. Salisbury et al (eds.), U.S. Govt. Printing Office, Washington, D.C., 689-698.

BLAISE, B., B.D. BORNHOLD, H. MAILLOT and R.G. CURRIE. 1984. Sedimentation near the Dellwood Knolls, northern Juan de Fuca Ridge system. *Eos, Trans. Am. Geophys. Union*, **65**: 1112.

BORNHOLD, B.D. and A.D. COLLINS. 1984. Surficial sediment distribution, Lasleek Brank, Hecate Strait. *GSC Open File 1086*.

BORNHOLD, B.D. and C.J. YORATH. 1984. Surficial geology of the continental shelf, northwest Vancouver Island. *Marine Geology*, **57**: 89-112.

CHAN, E., H.W. DOSSO, L.K. LAW, D.R. AULD and W. NIENABER. 1983. Electromagnetic induction in the Queen Charlotte Islands region – analogue model and field station results. *J. Geomag. Geoelectr.*, **35**: 501-516.

- CIESIELSKI, P., G. GRINSTEAD and B.D. BORNHOLD. 1984. Late Miocene to Piocene fluctuations of the polar front in the southwest Atlantic. *Geol. Soc. Am. Abstr. with Prog.*
- COLLINS, A.D. and B.D. BORNHOLD. 1984. Sediment distribution and surface morphology on the Kyuquot Uplift, west of Vancouver Island. *GSC Open File* 1085.
- CONWAY, K. and J.L. LUTERNAUER. 1984. Longest core of Quaternary sediments collected in Queen Charlotte Sound, B.C. *Geol. Survey Can. Paper* 84-1A: 647-649.
- CURRIE, R.G., E.E. DAVIS, R.P. RIDDIHOUGH and D.M. HUSSONG. 1984. Acoustic imagery of the Pacific-America-Explorer triple junction. *Eos, Trans. Am. Geophys. Union*, **65**: 1110.
- DAVIS, E.E. and T.J. LEWIS. 1984. Heat flow in a back-arc environment – Intermontane and Omineca crystalline belts, southern Canadian cordillera. *Can. J. Earth Sci.*, **21**: 715-726.
- DAVIS, E.E., J. SCLATER and C. LISTER. 1984. Towards determining the thermal state of old oceanic lithosphere. *Geophys. J.R. Astron. Soc.*, **78**: 507-545.
- DAVIS, E.E., R.G. CURRIE et al. 1984. Juan de Fuca Ridge atlas – SeaMARC II acoustic imagery. *EPB Open File* 84-16.
- DAVIS, E.E., S. HAMMOND et al. 1984. Juan de Fuca Ridge atlas – preliminary SEABEAM bathymetry. *EPS Open Files* 84-6 and 84-16.
- DAVIS, E.E. R.G. CURRIE, R.P. RIDDIHOUGH et al. 1984. Geological mapping of the northern Juan de Fuca and Explorer Ridges using SeaMARC I and SeaMARC II and SEABEAM acoustic imaging. *Eos, Trans. Am. Geophys. Union.*, **65**: 1110.
- DRURY, M.J., A.M. JESSOP and T.J. LEWIS. 1984. The detection of groundwater flow by precise temperature measurements in borehole. *Geothermics*, **13**: 163-174.
- DRURY, M.J., A.M. JESSOP and T.J. LEWIS. 1984. Geothermal logging for the detection of groundwater flow. In: *Proc. Internat. Conf. on Groundwater and Man*.
- DELAURIER, J.M., D.R. AULD and L.K. LAW. 1983. Geomagnetic response across the continental margin off Vancouver Island – comparison of results from numerical modelling and field data. *J. Geomag. Geoelectr.*, **35**: 517-528.
- HAMILTON, T.S. and W.D. ROOTS. 1984. Large scale mantle convection – implications for volcanism and magma segregation. *Eos, Trans. Am. Geophys. Union*, **65**: 273.
- HYNDMAN, R.D. and M.H. SALISBURY. 1984. The physical nature of oceanic crust on the mid-Atlantic Ridge, Deep Sea Drilling Project Hole 395A. In: *Init. Rep. Deep Sea Drilling Project, 78B*, R.D. Hyndman, M.H. Salisbury et al (eds.), U.S. Govt. Printing Office, Washington, D.C., 839-848.

HYNDMAN, R.D., N.I. CHRISTENSEN and M.J. DRURY. 1984. The physical properties of basalt core samples from Deep Sea Drilling Project Leg 79B Hole 395A. In: *Init. Rep. Deep Sea Drilling Project, 78B*, R.D. Hyndman, M.H. Salisbury et al (eds.), U.S. Govt. Printing Office, Washington, D.C., 801-810.

HYNDMAN, R.D., M.S. LANGSETH and R.P. VON HERZEN. 1984. A review of Deep Sea Drilling Project geothermal measurements through Leg 71. In: *Init. Rep. Deep Sea Drilling Project, 78B*, R.D. Hyndman, M.H. Salisbury et al (eds.), U.S. Govt. Printing Office, Washington, D.C., 813-823.

IRVING, E. 1984. Book review of Wandering Continents and Spreading Sea-floors on an Expanding Earth by L.C. King. *Phys. Earth and Planet. Int.*, **35**: 301-302.

IRVING, E. and D.F. STRONG. 1984. Paleomagnetism of the early Carboniferous Deer Lake group western Newfoundland—no evidence for mid-Carboniferous displacement of "Acadia". *Earth Planet. Sci. Lett.*, **69**: 379-390.

IRVING, E. and D.F. STRONG. 1984. Evidence against large-scale Carboniferous strike-slip faulting in the Appalachian-Caledonian orogen. *Nature*, **310**: 762-764.

JESSOP, A.M., T.J. LEWIS, A.S. JUDGE, A.E. TAYLOR and M.J. DRURY. 1984. Terrestrial heat flow in Canada. *Tectonophysics*, **103**: 239-261.

JESSOP, A.M., J.G. SOUTHER, T.J. LEWIS and A.S. JUDGE. 1984. Geothermal measurements in northern British Columbia and the southern Yukon Territory. *Can. J. Earth Sci.*, **21**: 599-608.

LANGSETH, M.S., R.D. HYNDMAN, K. BECKER, S.H. HICKMAN and M.H. SALISBURY. 1984. The hydrothermal regime of isolated sediment ponds in mid-oceanic ridges. In: *Init. Rep. Deep Sea Drilling Project, 78B*, R.D. Hyndman, M.H. Salisbury et al (eds.), U.S. Govt. Printing Office, Washington, D.C., 825-837.

LEWIS, T.J. 1984. Geothermal energy from Penticton Tertiary outlier, British Columbia—an initial assessment. *Can. J. Earth Sci.*, **21**: 181-188.

LEWIS, T.J., H.J. BENNETTS, V.S. ALLEN and F. CHAN. 1984. Uranium, thorium and potassium concentrations and heat generated in samples of crustal rocks—a data file. *EPB Open File 84-15*: 163 pp.

LUTERNAUER, J.L. 1984. Skeena, Nanaimo and Cowichan river deltas and offshore environs, B.C.—surficial sediment distribution and locations of other available data types collected by the Geological Survey of Canada. *GSC Open File 1112*.

LUTERNAUER, J.L. 1984. Sedimentary setting and character of sand and gravel bedforms on the open continental shelf off western Canada—status of knowledge. *Can. Soc. Petrol. Geol. Abstr. with Prog.*

- LUTERNAUER, J.L., D. DUGGAN and M. HENDRY. 1984. Development-induced tidal flat erosion on the Fraser River delta. B.C. *GSC Paper* 84-1A: 75-80.
- NELSON, C.S. and B.D. BORNHOLD. 1984. Temperate continental shelf skeletal carbonate deposits. *Geobios., Mem. Spec.* **8**: 109-113.
- PRIOR, D.B. and B.D. BORNHOLD. 1984. Subaqueous delta morphology, Britannia Beach, Howe Sound. *GSC Open File* 1096.
- PRIOR, D.B. and B.D. BORNHOLD. 1984. Geomorphology of slope instability features, Squamish harbour, Howe Sound, British Columbia. *GSC Open File* 1095.
- PRIOR, D.B., B.D. BORNHOLD and M. JOHNS. 1984. Depositional characteristics of a submarine debris flow. *J. Geol.*, **92**: 707-727.
- RIDDIHOUGH, R.P. 1984. Recent movements of the Juan de Fuca Plate system. *J. Geophys. Res.*, **89**: 6980-6994.
- RIDDIHOUGH, R.P. and D.A. SEEMANN. 1984. Juan de Fuca Plate Map JFP8, gravity anomaly, 1:2,000,000. *EPB, EMR*.
- SAWYER, B.S., R.P. RIDDIHOUGH, E.E. DAVIS and R.G. CURRIE. 1984. Sidelit and perspective imagery of the Juan de Fuca and Explorer Ridges. *Eos, Trans. Am. Geophys. Union*, **65**: 1110.
- SWEENEY, J.F. 1984. Arctic tectonics – what we know today. *Geos.*, **13**(4): 8-10.
- SWEENEY, J.F., H.R. BALKWILL, R. FRANKLIN, U. MAYR, P. MCGRATH, E. SNOW, L.W. SOBSZAK and R.J. WETMILLER. 1984. North American continent-ocean transects programme, Corridor G, Somerset Island to Canada Basin. *GSC Open File* 1093/*EPB Open File* 84-21.
- VILLINGER, H. and E.E. DAVIS. 1984. Heat flow and bottom water temperature measurements from the rift valley of the northern Juan de Fuca Ridge. *Eos, Trans. Am. Geophys. Union*, **65**: 1111.
- WYNNE, P.J., E. IRVING and K. OSADETZ. 1983. Paleomagnetism of the Esayoo Formation (Permian) of northern Ellesmere Island – possible clue to the solution of the Nares Strait dilemma. *Tectonophysics*, **100**: 241-256.

APPENDIX III

Permanent Staff 1984

Institute of Ocean Sciences

A. Department of Fisheries and Oceans

Director General

Mann, C.R.; B.Sc., M.Sc. (N.Z.), Ph.D. (Brit. Col.),
D. Eng. (N.S. Tech), F.R.S.C.
Van Dusen, T.S.

Management Services Division

Chief of Division

Todd, N.A.; B.Sc. (Glasgow), M.A. (Carleton)

* Adamson, G.
Coldwell, J.H.
Cooper, B.J.
Curtis, J.N.
Doxey, K.
Drysdale, A.E.
Firth, C.
Gent, C.E.
Grills, C.J.
Hanmer, M.P.
Hope, T.
Keding, L.M.
Kroeger, K.
Lafortune, A.J.; B.A. (Manitoba)
Lapp, B.I.; B.A. (Victoria)
Lohrmann, B.A.; B.Sc. M.Sc. (Guelph)
MacMillan, B.C.
Oakfield, C.L.
Sabourin, J.T.
Smith, K.R.
Thomson, L.S.C.; B.A. (Sask.), B.L.S. (B.C.)
Tillie, D.G.
Van Eyk, W.J.
Watts, F.

Commissionaires:

Sgt. Price, D.W.
Sgt. Hull, N.S.B.
Comm. Alexander, F.
Comm. Ashton, B.
Comm. Hill, E.
Comm. Moe, L.
Comm. Moffat, H.
Comm. Morris, R.
Comm. Trerice, L.
Comm. Wilson, W.

* Left in 1984

Personnel

Regional Personnel Manager:

Hamilton, K.R.; B.A. (Brit. Col.)

Groves, L.D.; Dip. (Victoria)

Knapp, B.M.

Linguanti, S.C.

Olauson, E.J.

** Renstrom, M.

* Stevens, I.B.; CIMA (McMaster)

Trentelmann, E.

* Left in 1984

** Joined in 1984

Hydrography

Director of Hydrography:

Bolton, M.; C.L.S.

Ages, A.B.; B.A.Sc., M.A.Sc. (Brit. Col.), P. Eng.

Bell, R.D.

* Browning, P.C.

Canning, B.

Chan, L.M.

Chapeskie, R.

Coldham, F.A.

Collins, T.

Crawford, W.R.; B.Sc., M.A.Sc. (Waterloo),

Ph.D. (Brit. Col.)

Crowley, J.V.; C.L.S.

Crowther, W.S.; CC (Ont. Inst. of Chartered
Cartographers)

Curran, T.A.; B.A.Sc. (EE), M.Sc. (Brit. Col.),
P. Eng.

Czotter, K.L.; Dip. BCIT

Dobson, D.G.

Dorosh, L.W.; Dip. BCIT

Douglas, A.; B.Sc. (Victoria)

Earl, E.L.P.

Eaton, G.H.; Dip. BCIT, B.Sc. (UNB)

Farmer, P.M. Fisher, D.L.

Galloway, J.L.; B.A.Sc. (EE), M.A.Sc. (EE)
(Brit. Col.), P. Eng.

Gould, J.

Halcro, K.; Dip. BCIT

Hare, R.; Dip. BCIT

* Harrison, D.W.

* Hartung, W.

Hermiston, F.V.

Hinds, E.W.; Dip. BCIT

Hinds, S.D.

Hohl, M.

Hollinger, C.; Dip. BCIT

Holman, K.R.

Huggett, W.S.; Master (FG), C.L.S.

Jackson, D.

Jennings, M.

** Jodrell, D.A.

Johnson, B.A.; Dip. BCIT

Kenny, B.

Kidson, G.

Korhonen, R.K.

Larken, J.B.; B.Sc. (PEI)

Lee, K.S.

** Lewis, B.V.; Dip. BCIT

Loschiavo, R.; Dip. BCIT

Lusk, B.C.; Master (350T), C.L.S.

Lyngberg, K.; Dip. BCIT	Sargent, E.D.; Dip. BCIT
Lyon, A.G.	Schofield, A.
MacPhail, G.	Schofield, B.
McGregor, B.G.; Dip. BCIT	Smedley, A.J.; L. Cdr. RCN (Ret'd)
Milner, P.R.; Dip. BCIT	Smith, A.; Master (FG)
Moody, A.E.	Smith, G.R.; B.A.Sc. (ME) (Brit. Col.), P. Eng.
Mortimer, A.R.; Master (FG), B.Sc. (Victoria), C.L.S.	Steebles, J., Cert. Mech. Eng. (Edinburgh)
Muse, R.A.; Trade Cert. CAF	Stephenson, F.E.; B.Sc. (Victoria)
Nowak, C.; Dip. BCIT	* Taylor, R.G.
* Osborne, M.	Taylor, W.R.; Dip. BCIT
Parks, J.R.; B.A.Sc. (EE) (Brit. Col.)	Thompson, L.G.
* Patton, M.M.	Thomson, A.D.; Dip. BCIT
Pfluger, H.	Tuck, B.
Philp, A.R.	Vear, M.
Pickell, L.M.	* Vosburgh, J.A.; Dip. BCIT, C.L.S.
Pierce, R.A.	Ward, M.M.; Dip. BCIT, B.A. (Lakehead)
* Pite, H.	Watt, B.M.
Popejoy, R.D.	Whincup, G.
Rapatz, W.J.; B.Sc. (Victoria), C.L.S.	* Wigen, S.O.; B.A.Sc. (Brit. Col.), P. Eng.
Raymond, A.R.; Dip. (Algonquin College)	*** Woods, M.V.; Dip. BCIT
Redman, D.	Woodward, M.J.; B.Sc. (Victoria), M.Sc. (Toronto)
Richardson, G.E.; C.L.S.	Woppard, A.; B.Sc. (Victoria)
Roberts, J.W.; Master (FG), Cdr. RCN (Ret'd)	Woolley, R.; Dip. BCIT
Ross, A.D.; CC (Ont. Inst. of Chartered Cartographers)	Yee, J.
** Salish, J.P.	* Left in 1984
Sandilands, R.W.; Lt. (H) RN (Ret'd), C.L.S. FRGS	** Joined in 1984
	*** Educational Leave

Ship Division

Regional Marine Superintendent:

Parkinson, R.W.; Engineer 1st Class, Member;
Institute of Marine Engineers

Fitch, L.A.H.; Master, H.T.; Assist. Marine
Superintendent
Doyle, D.A.; Secretary
Craton, M.; Administrative Clerk

CSS PARIZEAU

Chamberlain, A.G.; Master F.G., Master
Gilbert, J.; O.N. 1, 1st Officer
Coombes, A.; O.N. 1, A/2nd Officer
Gimbel, K.; W.K.M., 3rd Officer
Winterburn, G.; Eng. 1st Class Motor,
Chief Engineer
Tran, K.; Eng. 2nd Class Motor, Senior 2nd
Engineer
Miller, S.; Eng. 4th Class Motor, 2nd Engineer
Dowhy, J.; Eng., 3rd Engineer
Purdie, D.; Eng. 4th Class Motor, 4th Engineer
Palmer, S.; Supply Officer
Clarke, L.E.
Begoray, N.
Weston, A.
Prunkl, W.
Tighe, G.
Cooke, S.
Palamar, V.
Smart, T.
Waistell, G.
Waterfall, J.
Camiot, M.
Smith, J.
Springett, B.
Brown, J.
Fidler, M.
Keene, A.
Fowke, K.
Knoblauch, D.
Laforest, B.
Law, S.

CSS VECTOR

MacKenzie, R.W.; Master H.T., Master
Wheeler, M.G.; Master H.T., 1st Officer
Campbell, J.; Mate H.T., 2nd Officer
Pearson, R.; Eng. 3rd Class Motor,
Chief Engineer
Burrell, R.; Eng. 3rd Class Motor,
2nd Engineer
Thompson, D.; Eng. 4th Class Motor,
A/3rd Engineer
Braithwaite, P.
Robie, D.J.
Anderson, D.D.
Napier, J.
Simpson, F.
Lavigne, R.
McKechnie, D.
Burns, R.G.
Murphy, P.
Kirkby, D.B.
White, R.M.

CSS RICHARDSON

LeGarff, J.; W.K.M., Master
Jamieson, T.
Scott, R.
Temple, D.

CSS JOHN P. TULLY

Pereira, P.B.; Eng. 1st Class Combined,
Chief Engineer
McRae, A.

PISCES IV

Chambers, F.J.; Chief Pilot
Taylor, R.H.
Witcombe, A.
Oszust, J.
Shepherd, K.
Holland, R.

SHORE PARTY AND RELIEF POOL

Newton, B.L.; Master F.G.
Elliott, H.; O.N.II
Beebe, E.; Eng. 4th Class Motor
Stanway, J.D.; Eng. 4th Class Combined
Moore, A.; Eng. 4th Class Motor
Allison, G.
Lovelace, R.
Sanderson, R.
Simmons, B.
Williams, L.

DECK MACHINERY

Bradbury, J.D.

INSTITUTE WORKSHOPS

Smith, F.V.; Supervisor
McNeill, J.; Foreman
Badminton, E.
Barlow, L.
Bell, W.
Ennis, J.
Green, G.
Gurney, J.
Nelson, B.
Noren, R.
Smith, G.
Thompson, B.R.
Williams, P.

Ocean Information

Chief of Division:

- * Cornford, A.B.; B.Sc. (McMaster),
Ph.D. (Brit. Col.)
- Giovando, L.F.; B.A., M.A., Ph.D. (Brit. Col.)
- Glover, K.T., B.A. (UNB)
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* Left in 1984

Ocean Chemistry Division

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F.R.S. Chem. (U.K.), F.C.I.C.

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O'Brien, M.C.; B.Sc. (Alberta)
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Poulin, J.G.
Smith, G.L.; Dip. NAIT
Soutar, T.J.; Dip. BCIT
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Ocean Physics Division

Chief of Division:

Garrett, J.F.; B.A. (Harvard), Ph.D. (Brit. Col.)	Lake, R.A.; B.Sc. (Brit. Col.), M.Sc. (Washington)
Bell, W.H.; B.A.Sc. (Brit. Col.), M.Sc. (Hawaii), P. Eng.	Lee, A.Y.P.; B.Sc. (Victoria)
Bennett, A.F.; B.Sc. (U. of Western Australia), M.S., Ph.D. (Harvard)	Lewis, E.L.; B.Sc., M.Sc., Ph.D. (London)
Bigham, R.W.	Love, J.
Budgell, W.P.; B.A.Sc. (Waterloo), M.Eng. (McMaster), Ph.D. (Waterloo)	Mathias, A.L.
Chase, G.W.; Dip. BCIT	Meikle, J.H.
Cooke, R.A.; Dip. RCC	Melling, H.; B.Sc., M.Sc., Ph.D. (Toronto)
Crean, P.B.; B.Sc. (Dublin), M.A.Sc. (Toronto), Ph.D. (Liverpool)	Minkley, B.G.; Dip. BCIT
de Jong, C.	Miyake, M.; B.S. (EE) (Drexel), M.S., Ph.D. (Washington)
Delacretaz, A.	Moonie, J.A.
Farmer, D.M.; B.Comm., M.Sc. (McGill), Ph.D. (Brit. Col.)	Moorhouse, S.W.
Francis, D.B.; B.Sc. (Victoria)	Murty, T.S.; B.Sc., M.Sc. (Andhra), M.S., Ph.D. (Chicago)
Freeland, H.J.; B.A. (Essex), Ph.D. (Dalhousie)	Perkin, R.G.; B.A.Sc., M.Sc. (Brit. Col.)
Gargett, A.E.; B.Sc. (Manitoba), Ph.D. (Brit. Col.)	Quay, L.
Gower, J.F.R.; B.A., M.A., Ph.D. (Cantab)	Richards, D.L.
Henry, R.F.; B.Sc. (Edinburgh), Ph.D. (Cantab)	Spearing, L.A.F.; B.Sc. (Brit. Col.)
Holloway, G.; B.A., M.S., Ph.D. (California)	Stickland, J.A.
Johnston, P.	Stucchi, D.J.; B.A.Sc. (York), M.Sc. (Dalhousie)
Kamitakahara, G.R.; B.Sc. (Toronto)	Sudar, R.B.; B.A.Sc. (Toronto)
Koppel, A.W.	Tabata, S.; B.A., M.A. (Brit. Col.), D.Sc. (Tokyo)
Kimber, P.M.	Teichrob, R.C.; Dip. BCIT
	Thomson, R.E.; B.Sc., Ph.D. (Brit. Col.)
	Topham, D.R.; D.L.C., D.C.A.E., Ph.D. (Loughborough)
	Wallace, J.S.
	Wu, L.S.C.; B.Sc. (Brit. Col.)

Computing Services

Head:

Teng, K.; B.A.Sc., M.A. (Brit. Col.)
Douglas, A.N.; B.Sc. (Victoria)
Foreman, M.G.; B.Sc. (Queen's), M.Sc. (Victoria)
Green, J.W.; B.Sc. (Victoria)
Johns, R.E.; B.Sc. (Victoria), M.Sc. (Brit. Col.)
Lee, D.K.; B.S. (Chosun-Korea), M.S. (Oregon)
Lee, K.S.; B.Sc. (Victoria)

Linguanti, J.; B.Sc. (Victoria)
Ma, A.C.; B.Sc. (Victoria)
*** Oraas, S.R.; B.A.Sc., M.A.Sc. (Brit. Col.)
Page, J.S.; B.Sc. (Brit. Col.)
Smith, L.J.; B.Sc. (Simon Fraser)
Woppard, A.L.; B.Sc. (Victoria)

*** Interchange Program

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Pacific Geoscience Centre

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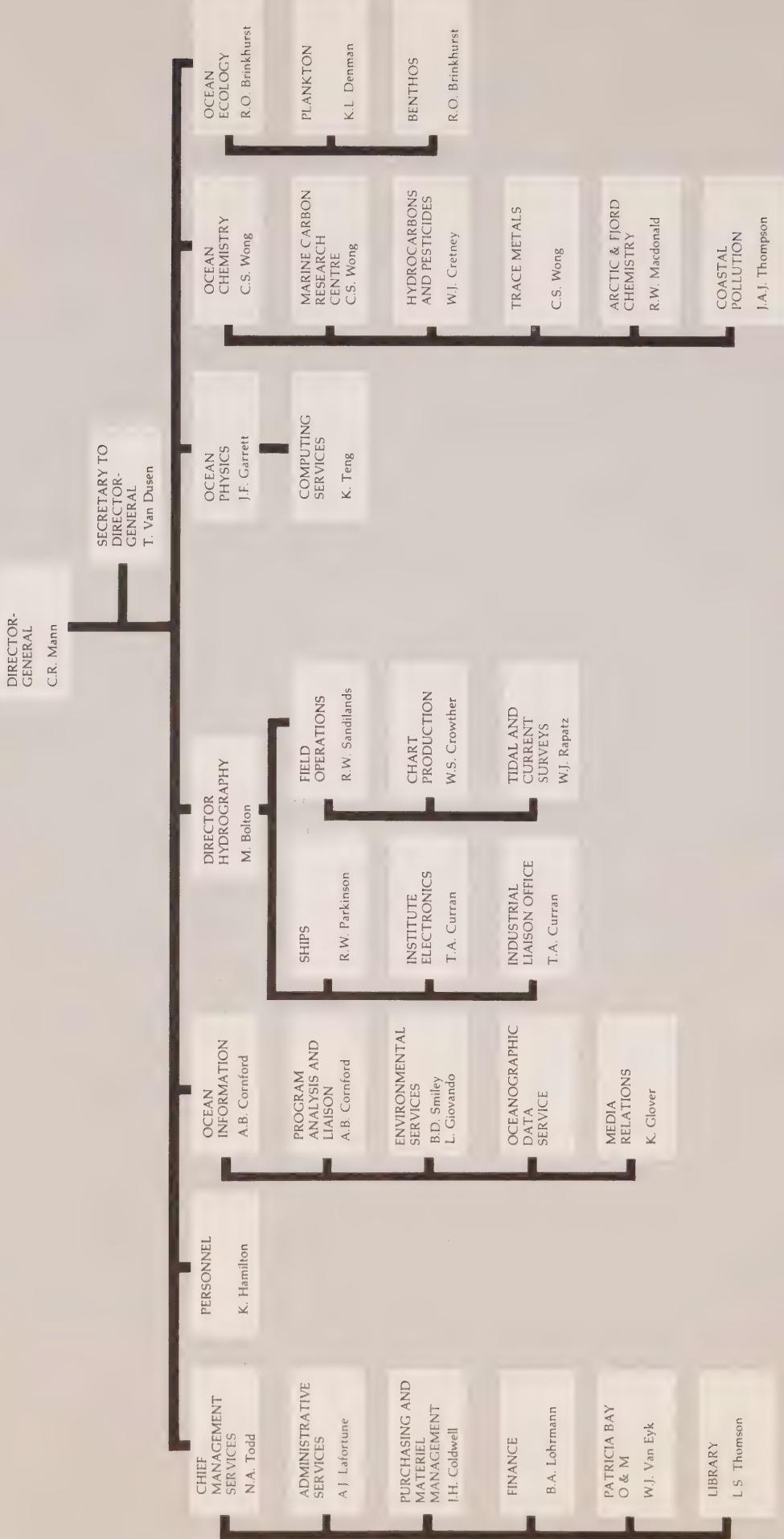
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 ** Joined in 1984

Organization Chart

Department of Fisheries and Oceans



1984
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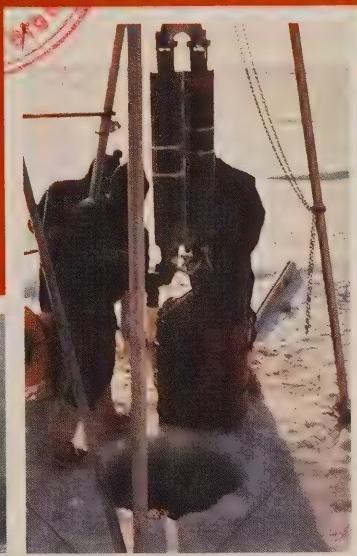


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1985 ANNUAL REVIEW OF ACTIVITIES

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Institute of Ocean Sciences, Patricia Bay

1985

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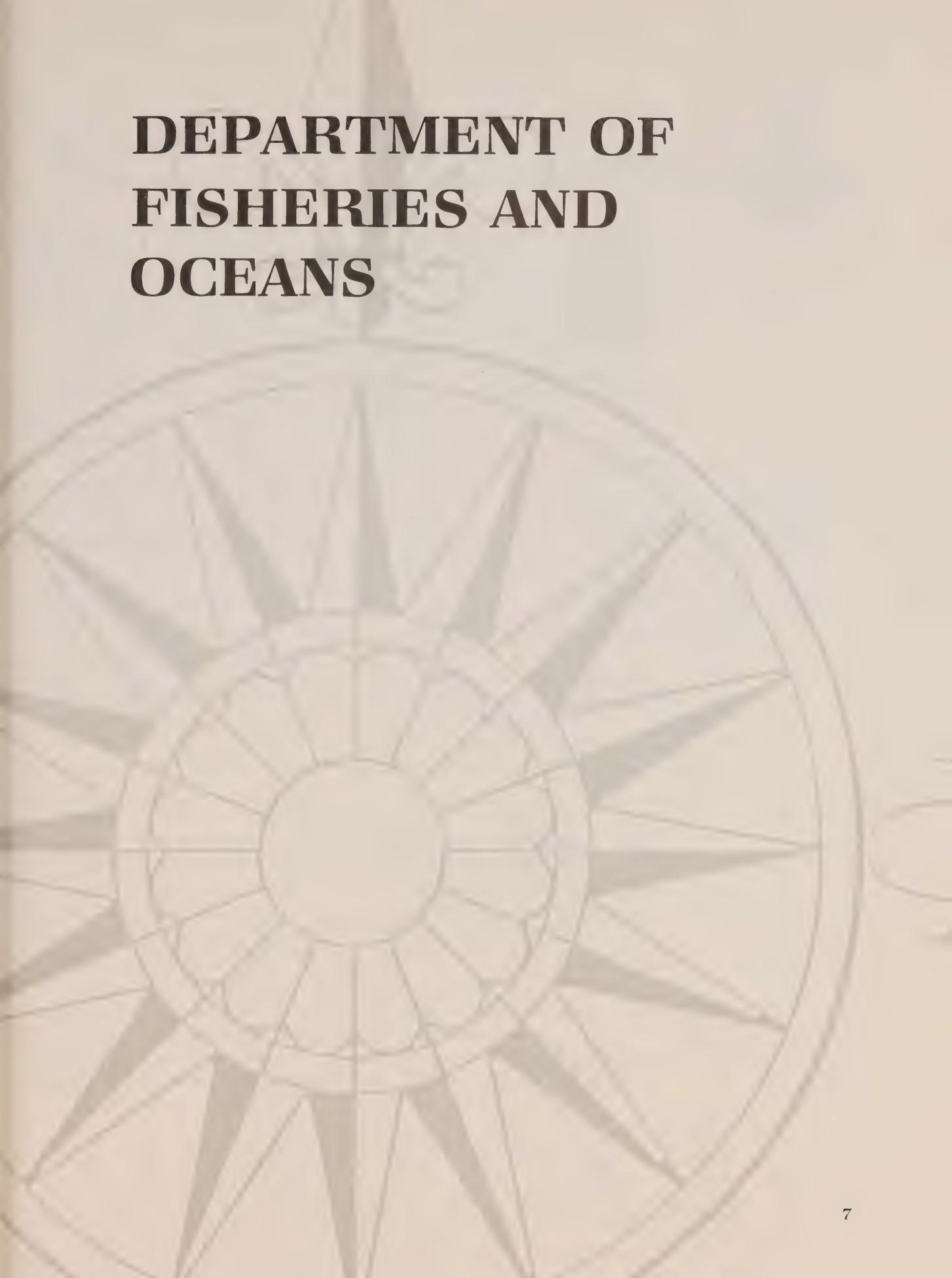
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DEPARTMENT OF FISHERIES AND OCEANS



Director-General's Foreword



In October of this year, Mike Bolton retired as Director of the Pacific Region of the Canadian Hydrographic Service located at the Institute of Ocean Sciences (IOS). He had done a great deal in the past 17 years to develop hydrography on the Pacific coast. His place is taken by Tony O'Connor who is looking forward to the challenge of continuing Mike's work. The Institute also took delivery of a new vessel, the *CSS John P. Tully*, named after John Tully, the pioneer of oceanography on the west coast of Canada. She is not a large vessel, being only 69 metres in length, but she has an extra deck which gives her an astonishing amount of laboratory space. She also carries four modern survey launches. The *John P. Tully* is the replacement for the *Wm. J. Stewart* and joins the IOS fleet as a major hydrographic and oceanographic survey vessel.

If anything could be said to characterize this past year, I would say that it is the amount of application of our work to the solution of practical problems. A great deal of our program is devoted to acquiring information about the ocean that must be obtained before some of these problems can be solved. Our largest project over the past few years has been to describe the current systems and plankton ecology of the waters over the continental shelves. The majority of the work has been completed and it has allowed our scientists to develop joint programs with the Pacific Biological Station to study recruitment and survival in selected fisheries. The information also enabled us to speak with authority at the hearings held to determine the environmental consequences of oil exploration off the Queen Charlotte Islands.

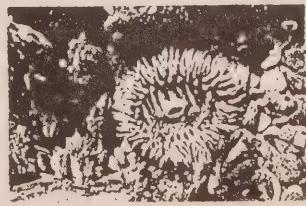
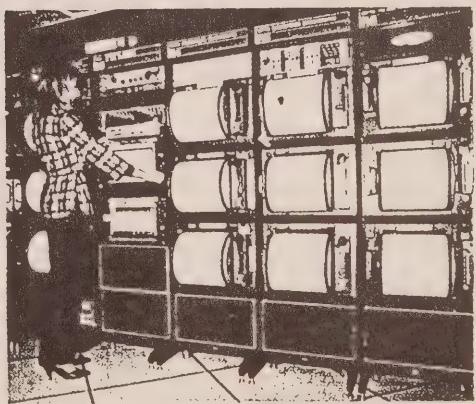
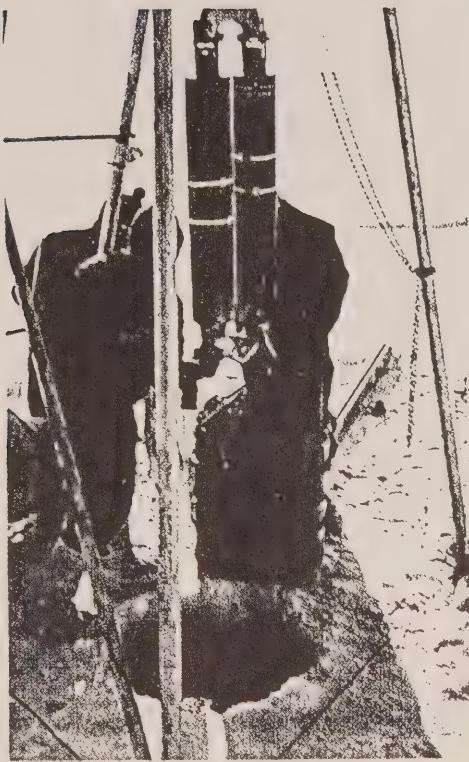
We have also been active solving problems in the coastal areas which are described in the main of the report. Our Chart Production and Distribution section had a banner year and produced two special charts; one for Expo 86 and the other of the Broken Group of Islands in cooperation with the Pacific Rim National Park. The reverse side of the latter chart depicts illustrations of marine life and includes general information relative to activities in the area. Cartography staff also produced a 29-page cruising atlas for the Jervis Inlet/Desolation Sound area.

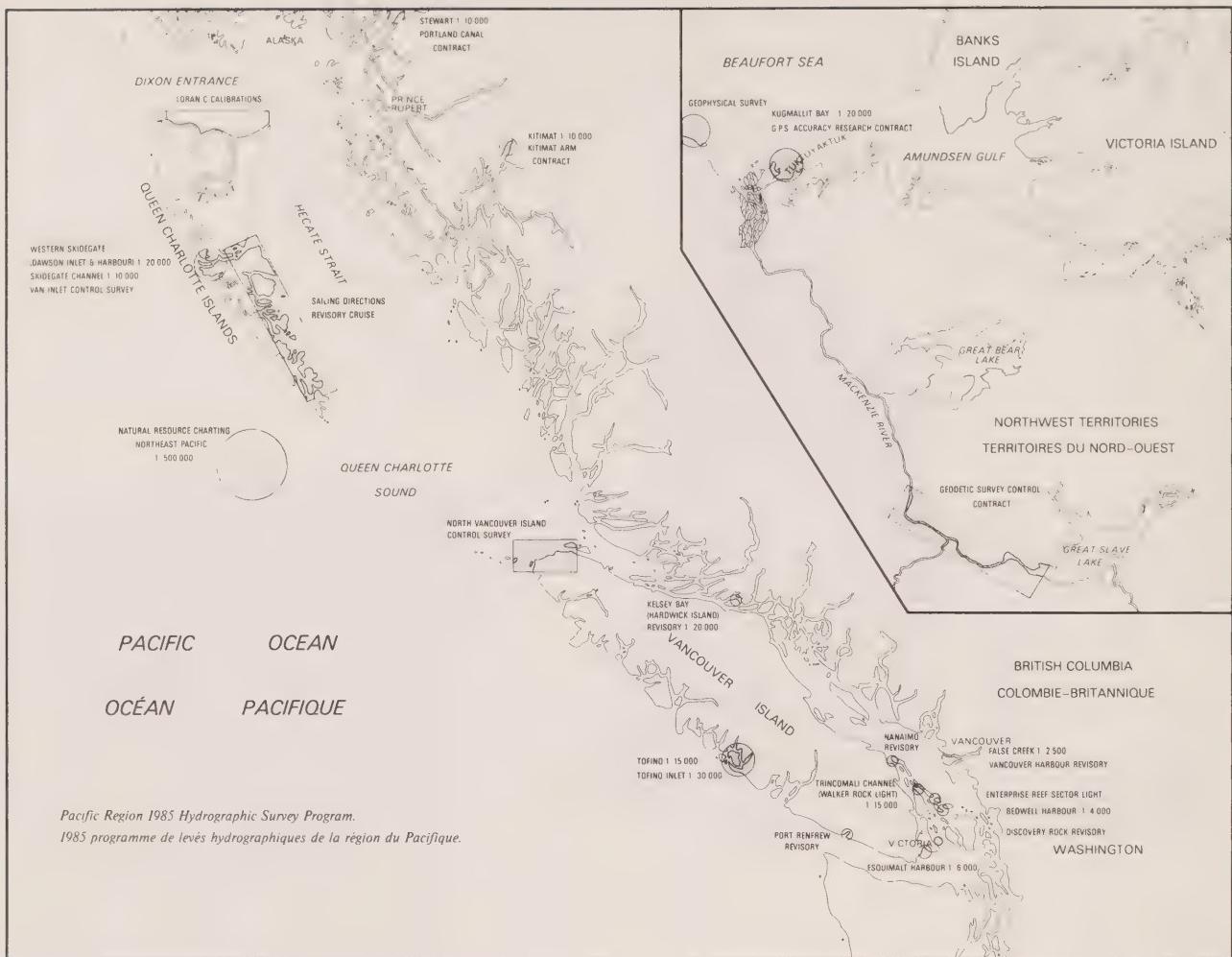
In the Arctic, our main thrust has been to upgrade our knowledge of the oceanography of the Beaufort Sea and to work with the Atmospheric Environment Service to improve ice forecasting. In 1986, using additional resources provided through the Northern Oil and Gas Action Plan, the

work will be expanded to include ecology and chemistry.

The deep-sea oceanography and modelling program we are developing for climate research has not gone as fast as I would have liked because it has not been possible to obtain additional resources. There is no doubt in my mind that this is an important line of research and that the Institute must continue with it as there is such a great potential payoff for the management of natural resources. Despite not being able to enhance the program, our scientists are making significant contributions to climate research, particularly to the problem of determining the capacity of the oceans to absorb CO₂.

Hydrography





Hydrography



The Hydrographic Division supports and conducts the field studies necessary to meet a planned publication schedule of nautical charts, tide tables, current atlases and sailing directions. The Division's area of responsibility includes the coast of British Columbia, the western Arctic and the inland navigable waters east to the Saskatchewan-Manitoba border.

Specific activities of the Division in fulfilling its mandate are reported in the following sections but perhaps the highlight of the year was the acceptance of the new research vessel, *John P. Tully*. Despite the worst ice conditions experienced in several years, this fine new ship had a successful maiden voyage to the Beaufort Sea.

Long-time Regional Director of Hydrography, Mike Bolton, retired in October, 1985; he will be missed by all Institute of Ocean Sciences (IOS) personnel.

Field Hydrography



The Field Hydrography Section is responsible for conducting hydrographic surveys of the B.C. Coast, western Arctic and navigable inland waters in the Pacific region to ensure that requirements for navigational information are met. Alterations of, and additions to, traffic routes, types and sizes of vessels, harbours, bottom topography and coastline—all require an ongoing and resurvey program.

The major coastal survey party was assigned to the barge *Pender* from April to October. A resurvey of False Creek, the site of Expo 86, was necessitated by the removal of bridges, addition of marinas, major construction on the north shore and considerable dredging. On completion of this resurvey the barge moved to Tofino where a continuing resurvey of the area was commenced. (*Contact: G.E. Richardson.*)

CSS *John P. Tully*, on her maiden voyage, sailed for the western Arctic in July and commenced a series of surveys north of Tuktoyaktuk in the



Barge Pender alongside CCG Base Kitsilano during False Creek survey.

Kugmallit Bay area. This survey was hampered by poor ice conditions and the level of results was less than anticipated. (*Contact: B.M. Lusk.*)

At the beginning of September, the *Tully* moved west to the area Herschel Island to the Alaska/Yukon boundary to complete the geophysical portion of a multidisciplinary survey of the area commenced in 1984. (*Contact: G.H. Eaton, IOS, or S. Blasco, Atlantic Geoscience Centre (AGC).*)

CSS *Richardson* completed the survey of Skidegate Channel and resurveyed Dawson Harbour and Inlet in June and July. In August, further Loran C calibrations were carried out in Dixon Entrance. (*Contact: A.R. Raymond.*)

A resurvey of Esquimalt Harbour was commenced and several local revisory surveys were completed by IOS-based survey parties. (*Contact: F.A. Coldham.*)

Control survey work on the north coast of Vancouver Island was carried out in preparation for future resurveys. (*Contact: M.V. Woods.*)

Navigational and bathymetric support was provided for a Pacific Geoscience Centre (PGC) natural resource survey in the northeast Pacific. (*Contact: P.R. Milner.*)

Under contracts, revisory surveys of Stewart and Kitimat were completed and survey control was run on a section of the Mackenzie River.

Hydrographic Development

Datalogging and processing hardware and software once again received significant attention. Indeed, it now appears correct to regard the annual changes as software maintenance. To this end, the logging software was modified to accept GPS (Global Positioning System) and Syledis data, and an automated range-bearing software technique was incorporated into the system. The logger software kernal was also modified to permit 32-bit addressing. Three commercial dataloggers (ISAH) were purchased in 1985, one of which includes data processing. They resulted from a technology transfer under the NRC PILP program.

A contract to improve long-range ARGO data was started with a private company, but proceeded slowly.

The laser bathymetry project (LARSEN 500) was transferred to the CHS Pacific for continued development and ultimate transfer to industry. This system, presently mounted in a DC-3 aircraft, reliably detects water depths to 30 metres in the clear Arctic waters. (*Contact: T.A. Curran.*)

Sailing Directions

The Thirteenth Edition of the *British Columbia Coast Sailing Directions (South Portion), Volume I*, was published in January, and the Tenth Edition of the *British Columbia Coast Sailing Directions (North Portion), Volume II*, was published in July. These editions contain new information on tidal streams, vessel traffic services, Loran C and port facilities. New photography and several new diagrams were incorporated into these editions. Normally these editions are published in alternate years.

The Sixth Edition of the *Great Slave Lake and Mackenzie River Sailing Directions* was published in May. This edition contains much new information gathered on field inspection since the previous edition published in 1981. (*Contact: A. Smith.*)

Field inspection for revisions was carried out on the east coast of the Queen Charlotte Islands.

Chart Production and Distribution

The functions of the Chart Production and Distribution Section are to ensure that survey and other pertinent data are processed for publication



as expeditiously as possible and to ensure that a ready supply is available for all users.

Eight standard new charts were produced in Pacific Region in 1985 in addition to 46 new editions, 16 reprints, 9 chart amendment patches and 11 overprint editions.

The chart amendment staff processed 1.3 million corrections on 170,000 charts.

The chart sales and distribution office distributed 159,293 charts, 76,058 publications and 42,174 information brochures during the year.

Chart #	New Charts Released in 1985	Scale
3062	Pitt River and/et Pitt Lake	1:25,000
3499	Roberts Bank	1:15,000
3512	Strait of Georgia, Central Portion/Partie Centrale	1:80,000
3513	Strait of Georgia, Northern Portion/Partie Nord	1:80,000
3514	Jervis Inlet	1:50,000
3537	Okisollo Channel	1:20,000
3955	Plans—Prince Rupert Harbour	various
7600	Beaufort Sea/Mer de Beaufort	1:1,000,000
Chart #	New Charts Produced On Contract for Publication in 1986	Scale
7661	Demarcation Bay to/à Phillips Bay	1:50,000
7662	Mackenzie Bay	1:50,000
7663	Kugmallit Bay	1:50,000
7664	Liverpool Bay	1:50,000
7665	Franklin Bay and/et Darnley Bay	1:50,000
7666	Cape Lyon to/à Tinney Point	1:50,000
7667	Dolphin and Union Strait to/à Prince Albert Sound	1:50,000
7685	Tuktoyaktuk Harbour and Approaches/et les Approches	1:15,000

Sixteen Notices to Shipping and 136 Notices to Mariners were issued necessitating 173 chart amendment tracings.

The Hydrographic Data Centre processed 1000 plans from government agencies, 620 Marep Reports and provided 56 survey document requests.

Much time and effort was expended in 1985 in the production of a 29-page cruising chart for the Desolation Sound area and also a special chart for Expo 86.

A special chart of the Broken Group, #3670, was produced in cooperation with Pacific Rim National Park (Parks Canada). The reverse side depicts several illustrations of marine life and includes general information relative to activities in the area.

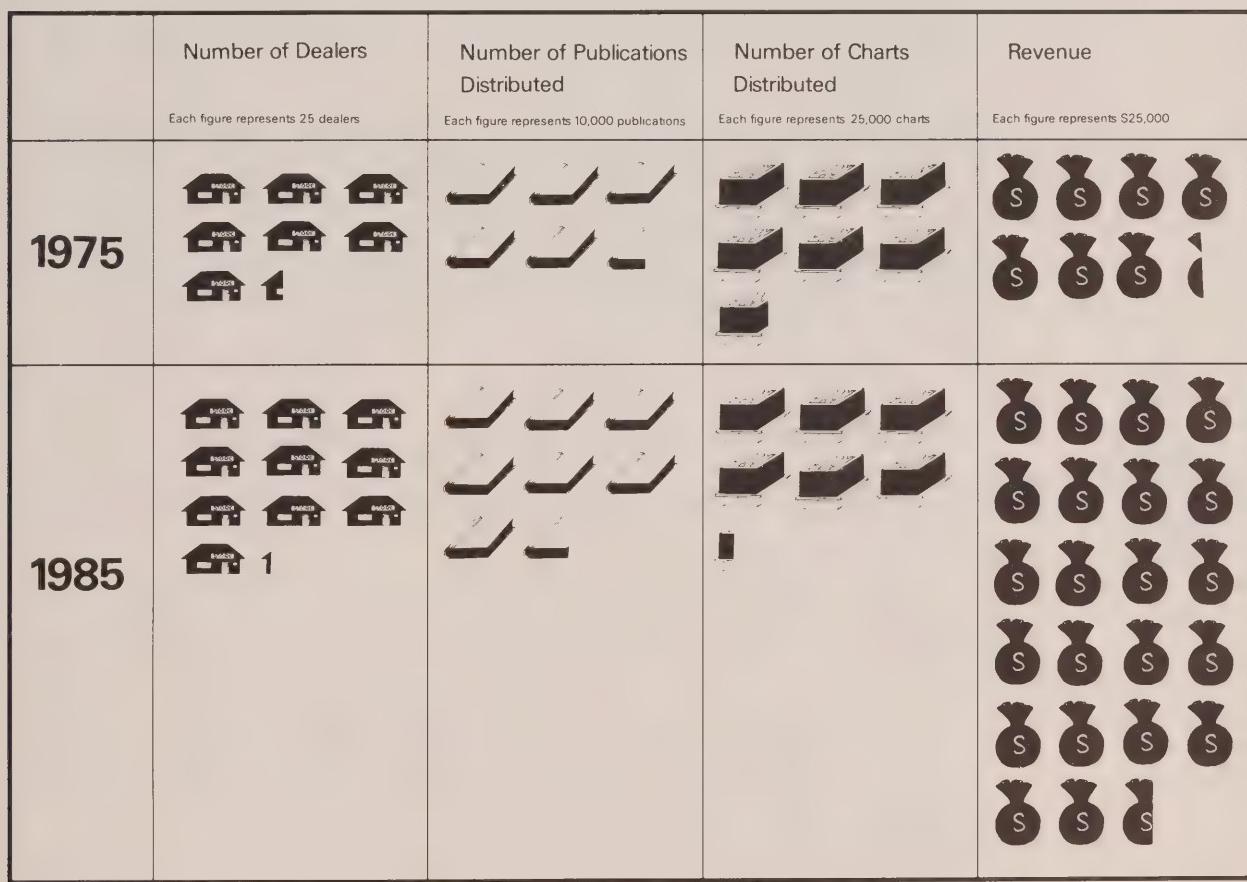


CHART DISTRIBUTION UNIT

GROWTH CHART

Two senior staff successfully completed CARTO II and another two attended the Senior Cartographic Seminar at Headquarters. Nine staff members attended the Introduction to Computers course at Camosun College and two more participated in the Middle Management Orientation Training Course at IOS. Three employees successfully completed the Canadian Power Squadron's Basic Boating Course and a fourth employee completed the Coastal Navigation Course at Camosun College.

Educational and promotional activities continued with participation in the Vancouver International Boat Show, the Pacific National Exhibition and the Canadian Power Squadron's National Conference. Various tours and lectures were provided for Canadian Power Squadrons and other students.

The phototypesetter (Berthold ACS 3200) installed in October 1984 is now being utilized to produce all type requirements for the region. In automated cartography, 1985 was the most productive year to date, with a record number of digital charts being produced. The acquisition of a DMZ32HS controller, a RA81 DEC disc drive and two megabytes of memory has increased production by allowing a greater number of files to be worked on simultaneously.



Tidal and Current Surveys

The field work for a study of the circulation in the waters surrounding the Queen Charlotte Islands was completed. All moorings in Dixon Entrance were recovered. Data are now being compiled and analyzed. Unexpectedly, strong currents (greater than three knots) were observed near Cape Chacon and Langara Island. Five additional offshore bottom-mounted tide gauges were deployed in Queen Charlotte Sound and recovered six months later, to confirm anomalies in the numerical model of Queen Charlotte Sound, Hecate Strait and Dixon Entrance. (*Contact: W.S. Huggett.*)

Current surveys in Sechelt Rapids and in Nakwakto Rapids were completed and the method of analysis refined. Much improved current predictions are now available for Nakwakto Rapids, Sechelt Rapids, Quatsino Narrows, Gabriola, Dodd, Porlier and Active Passes, and will appear in the 1987 Tide and Current Tables. These surveys will be extended to other narrow passes in 1986. (*Contact: M.J. Woodward.*)

A study of a cyclonic eddy west of the mouth of Juan de Fuca Strait was carried out jointly with the Ocean Ecology and Ocean Physics groups at IOS. A conductivity-temperature-depth (CTD) survey and a study of turbulent mixing, as well as ocean drifter studies, were undertaken. Drifter tracks are being merged with infrared satellite imagery to confirm the existence and extent of the cyclonic eddy. (*Contact: W.R. Crawford.*)

Time series observations in the Fraser River were continued with a new conductivity-temperature-depth-velocity (CTDV) meter developed at IOS. The numerical model of the Fraser was revised to include the capability to predict the tracks of objects. Observations are still being made jointly with Water Survey of Canada to measure the distribution of flow at the trifurcation point near New Westminster. (*Contact: A.B. Ages.*)

Field observations for a study of the Campbell River estuary, involving measurement of tides, currents, salinities, and temperature, were completed. Modelling of the estuary will include the salinity intrusion. This study is being carried out jointly with fisheries scientists at the Pacific Biological Station. Its objective is to discover how an environmental enhancement project carried out by B.C. Forest Products Ltd. might affect salmonid feeding grounds. (*Contact: A.B. Ages.*)

As in previous years, tidal records from 21 permanent and several temporary stations were processed and the data forwarded to Marine Environmental Data Service for archiving. Data from three gauging stations are forwarded to the Integrated Global Ocean Services System (IGOSS) each month as Canada's contribution to a Pacific mean sea level anomalies study. Tide gauges at Zeballos, Gold River, and Campbell River were operated to support a joint study with Pacific Geoscience Centre on earthquake-induced crustal movements. Planning and preliminary surveys were carried out to extend this study to Nanoose Bay and Kelsey Bay. (*Contact: F.E. Stephenson.*)

A program to obtain accurate information on tidal and long-term water level variations in Baffin Bay and along the Arctic coast of the Queen Elizabeth Islands was continued. This program will end in 1986. The data are expected to provide information on seasonal and annual variations in net transport through the Arctic Archipelago. (*Contact: F.E. Stephenson.*)

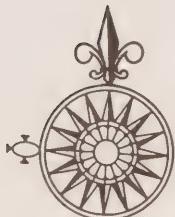
Two tsunami warning gauges, at Langara Island and at Tofino, were maintained and operated on a routine basis. The tide gauge station at Bamfield was modified to serve as a third tsunami warning gauge. It is now operating satisfactorily and is capable of transmitting information directly to the Tsunami Warning Centre at Honolulu, Hawaii.

A successful tsunami conference was held at IOS, sponsored jointly by Hydrography and Ocean Physics. The conference consisted of a Workshop on the Technical Aspects of Tsunami Analysis, Prediction, and Communications; the tenth meeting of the International Coordination Group for the Tsunami Warning System in the Pacific; and an International Tsunami Symposium sponsored by the Tsunami Commission of the International Oceanographic Commission (IOC). (*Contact: W.J. Rapatz.*)

Diving Unit

During 1985, 60 dives were carried out by the Diving Unit in support of activities at IOS. Diving activities can be summarized as follows: recovery of bottom-mounted tide gauges from sites in Dixon Entrance; inspection and/or servicing of the stilling wells, tide staffs and their supporting structures at tide stations on the Pacific coast; annual servicing of the permanent tide gauge network in the western Arctic; tests of survey launch noise conducted in Saanich Inlet; dives to inspect the propellers, zines and/or transducers of IOS ships as well as a survey of the *John P. Tully's* bottom paint; underwater modifications to an electronics test facility at the IOS wharf; observation of a trial of a through-ice deployment technique and recovery package for tide gauges; clearing the starboard propellor of an American pleasure boat which became fouled in an IOS mooring in Patricia Bay; and, training dives.

Some of our diving requirements in the Arctic (at Tuktoyaktuk and in the Queen Elizabeth Islands), to service tide gauges, were again carried out under contract. (*Contact: F.E. Stephenson.*)



Engineering Services

Engineering Services provides electronics and mechanical engineering and electronics support for hydrographic surveys; oceanographic research and ship operations; and an industrial liaison service promoting interaction between IOS, other government departments, and the private sector. (*Contact: T.A. Curran.*)

Engineering Development

This group provides custom development of hydrographic and

oceanographic instrument systems and consultations to all IOS groups.

Instrumentation projects under development in 1985 included a telemetering tide gauge, a Meteorburst tidal telemetry system, and development of a turbidity sensor.

The Active Drifter system underwent two offshore tests which were reasonably successful. Data were collected on the self-navigation performance.

Development of acoustic expertise continues to be a priority with Engineering Development. Standard modules are being constructed for basic signal processing tasks. Two competitive transducers were purchased to attempt to improve depth capability of the Skipper sounders. A narrowbeam acoustic telemetry project achieved rapid development this year. Slow-scan television pictures were transmitted over an acoustic link, and were the subject of a paper at Oceans 85 and three local seminars.

The SAIL system was installed on the *Tully* during the past year. A management decision was taken that ongoing accountability for proper operation of these systems will permanently reside within the group.

Several annoying electromagnetic interference problems in our launches were tackled toward the end of 1985. Some solutions are in hand, but others are still under development.

Contract supervision by the group included the Correlation Current Meter (now into the final phase), an acoustic release contract, a fibre optic refractometer, and completion of a laser diode pressure sensor. The latter contract did not achieve specifications, but led the company to two spinoff contracts. (*Contact: J. Galloway.*)

Institute Electronics

Calibration, repair, installation and routine maintenance of equipment in support of hydrographic and oceanographic programs and ship operations were successfully performed during the year. The major equipment areas were radios, depth sounders and digitizers, positioning systems and data loggers.

In the communications areas, approximately 69 VHF-FM and 15 HF/SSB transceivers were maintained. A remote display for the teletype over radio link (TOR) was established in the Regional Ship Superintendent's office for direct hardcopy communication with IOS vessels. The Glenayre

message terminal system has proven very satisfactory and has been extended to six units.

The sonar group maintained 28 survey-type and navigational depth sounders, as well as numerous small digital sounders and 12 sounder digitizers. In addition, two velocimeters were serviced and maintained.

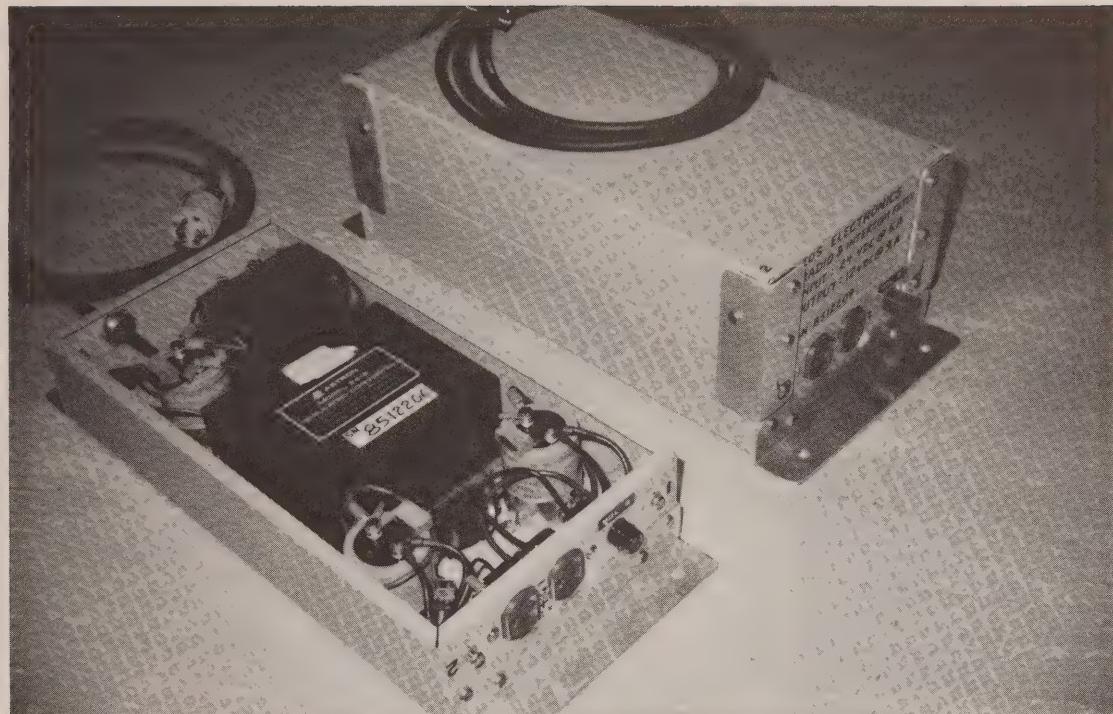


A typical configuration of electronics for inshore hydrographic survey. From port to starboard: distance measuring unit (DMU), VHF radio, Skipper echo sounder, monitor and HAL (hydrographic acquisition and logging) system keyboard, Qantex data storage and tape drive unit (top), MSI depth digitizer, HAL, and ARGO positioning system including the receiver, range positioning and control display units.

Approximately 21 microwave positioning units, 15 Argo units, two transit satellite navigation systems and several Loran C and Omega systems were serviced.

The five in-house datalogging systems (HAL) continue to provide excellent performance, and received routine hardware and software maintenance. Three commercial ISAH dataloggers/dataprocessors were acquired over the past year; they performed well.

Ships, launches and the barge *Pender* were fitted out for hydrographic purposes.



A filter, designed and installed by Institute Electronics, to reduce electromagnetic interference on launch installations.

Field support was provided for hydrographic survey on *Tully*, and local support was provided to local survey parties.

Continuing support was provided to Computing Services in the maintenance of the Kongsberg drafting system. (*Contact: W.R. Taylor.*)

Industrial Liaison and Contracting

IOS has an established policy of contracting out a significant portion of its program to the private sector. Liaison and support for contracting activities is conducted by the administrative staff of Engineering Services.

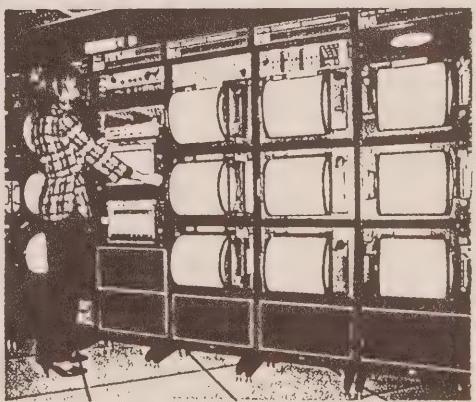
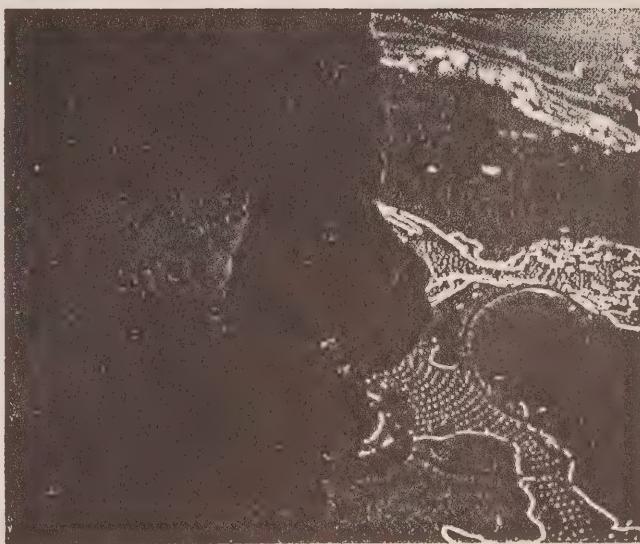
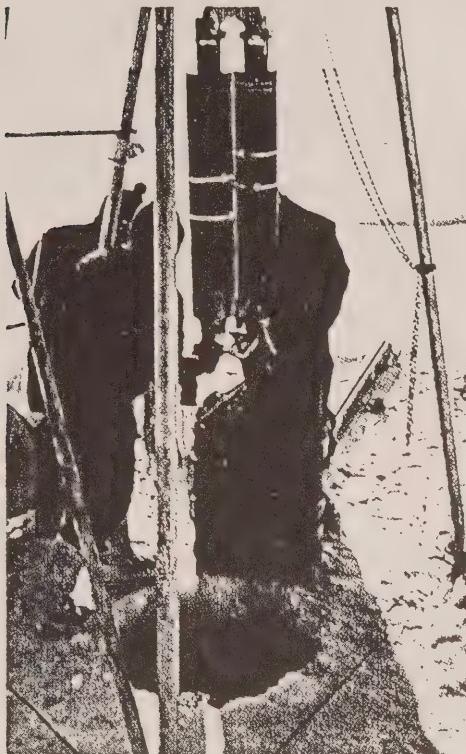
In addition to contracting out directly, IOS participates in such government ventures as the Unsolicited Proposals (UP) program with the Department of Supply and Services (DSS), and both the Program for Industry/Laboratory Projects (PILP) and the Industrial Research

Assistance Program (IRAP) with the National Research Council (NRC). IOS was involved to some extent in 116 contracts in the past year, ranging in value from less than one thousand dollars to approximately one million dollars, and with a total value in excess of \$4.8 million.

The NRC programs PILP and IRAP were consolidated under the IRAP name during the past year. Consequently, IRAP activities span the range from transfer of technology from government labs (including IOS) to labour-cost sharing agreements.

Increasingly, there is concern from the private sector regarding manufacturing rights and protection of fundamental technology developed in the labs. The crown corporation, Canada Patents and Development Limited, can provide this assurance and IOS is presently transferring administration and control of several technologies to CPDL.
(Contact: T.A. Curran.)

Oceanography



Ocean Physics



Fjords and Channels

In addition to continued work aimed at understanding and predicting the distribution of properties within fjords on the basis of external inputs, 1985 saw the first of a series of field programs to study the nature of mixing in tidal fronts. Simultaneous measurements of turbulent energy dissipation and vertical velocity were obtained in a tidal channel, which showed that the maximum turbulent dissipation was located well behind the front, even though the front contained downward vertical velocities as high as 40 cm/sec, which carried air bubbles to depths of 50 m.

(Contact: A.E. Gargett, D.M. Farmer.)

Straits

The extension of the two km mesh vertically integrated barotropic tidal model to cover the whole of the Georgia Strait/Puget Sound/Juan de Fuca Strait system was completed. After calibration, the model was used to generate tidal constituents for each grid point. These were then incorporated in a personal computer tidal current prediction program, developed by a contractor with IOS assistance. This has been delivered to the Environmental Protection Service and Canadian Coast Guard for use in real-time prediction of tidal currents in emergency situations. (Contact: P.B. Crean.)

The extension of the barotropic tidal model also permitted improvements to the "Fraser River plume" surface layer model. These improvements, and the addition of wind forcing, brought this model to the point where it is now capable of reproducing observed drifter tracks in all seasons.

(Contact: P.B. Crean.)

The last of the current meter arrays deployed in the passages of the Arctic Archipelago were recovered in April. In the last three years a total of 66 current meter records and 15 bottom pressure records have been obtained. Of these, eight current records and four pressure records are of 12-month duration. The reduction and analysis of this data in terms of tides and mean flow was begun, together with that of the water property surveys conducted during current meter deployment and recovery. Work

is proceeding on a triangular grid tidal model for the channels making up the Northwest Passage, with completion expected early in 1986.
(Contact: H. Melling, T.S. Murty.)

The first of two cruises to Gibraltar Strait was conducted in November, in cooperation with U.S. scientists on a U.S. vessel. The internal structure was mapped using acoustic techniques in conjunction with more conventional means. The objective is to test the theoretical conclusion that the exchange between the Mediterranean and Atlantic, which determines the properties of the Mediterranean, is controlled by the same internal hydraulic mechanisms as control the exchange over the sills in many B.C. fjords. *(Contact: D.M. Farmer.)*

Continental Shelf

The last phase of the field work in a 10-year program to obtain a basic description of oceanic conditions on the Pacific continental shelf was concluded with the recovery of the last moorings from the shelf west of the Queen Charlotte Islands in November. Data from earlier phases of the survey, off Vancouver Island and in Queen Charlotte Sound, have already yielded numerous publications and generated process-oriented experiments. The information was also used as the basis for presentations to the West Coast Offshore Exploration and Environmental Assessment Panel hearings. The general picture is one of complex flow patterns created by the interaction of large tides, rugged bottom topography, and seasonal variations in winds and coastal runoff. Off Vancouver Island the spatial pattern of tidal frequency currents is controlled by continental shelf wave dynamics. Vorticity associated with shear between offshore wind-drive flow and nearshore buoyancy (runoff)-driven flow generates a semi-permanent eddy locked to the bottom topography off the mouth of Juan de Fuca Strait. Further north, intensification of this shear by Brooks Peninsula results in eddy generation by baroclinic instability. In Queen Charlotte Sound, eddies are generated by the interaction of tidal currents with bottom topography. Whatever their origin, these eddies are the main contributor to the exchanges between the continental shelves and the open ocean offshore. *(Contact: R.E. Thomson, H.J. Freeland, W.R. Crawford.)*

A mooring array designed to measure the vorticity balance of the large eddy previously observed at the mouth of Juan de Fuca Strait was maintained for three months during the transition between winter and summer conditions. Although the vorticity was nearly constant during the latter part of the period, the closed streamlines of the eddy were

observed for only a portion of the time. (*Contact: H.J. Freeland.*)

A project designed to improve predictions of surface drift on the west coast of Vancouver Island, for use in developing search and rescue plans, was conducted jointly with the Canadian Coast Guard over the last two years. Satellite surface drifters were used to build up a data base, which was, in turn, incorporated in a predictive model by the contractor conducting the project. It is planned to extend this work to other areas as funds permit. (*Contact: R.E. Thomson.*)

Numerical models combining continental shelf dynamics, topography and simple models of plankton growth and nutrient transfer have been developed and time-lapse movies of the output constructed. They qualitatively reproduce many of the features seen in satellite water colour images of the Pacific Coast. The importance of various parameters can be estimated by varying them in the model. (*Contact: G. Holloway.*)

A current meter array was installed on the outer continental shelf in the Beaufort Sea, to complement earlier measurements and to determine whether the expected eastward jet exists over the shelf break. This current is suggested by water property distributions and various theoretical ideas. Numerical and theoretical studies of the current patterns on the Beaufort shelf indicate that topographic effects are very important. (*Contact: H. Melling, W.P. Budgell.*)

Images of the ice cover from satellite radiometers and airborne SAR are being collected and compiled. Where sufficient continuity exists, time-lapse animation sequences were compared. Ice motion vectors have been extracted from the imagery for use in estimation of the spatial and temporal correlation scales of ice motion. These statistics determine the limits of predictability, as well as suggesting which processes are most important in controlling ice motion. (*Contact: J.F.R. Gower.*)

A variety of techniques were used to obtain information on the details of the flow field under a pressure ridge keel. The form drag on such keels is thought to be the major source of coupling between ice and water, but existing parameterizations do not correctly represent the physical processes involved, particularly when the water column is stratified. A two-dimensional numerical model was developed for use in planning the experiment and interpreting the results. (*Contact: D.R. Topham.*)

Ice growth on the continental shelf forms dense brine which then drains across the shelf. The rate of brine drainage can limit ice growth, while the associated flow field is an important element of the winter circulation. The parameters controlling this process are being studied by

means of laboratory models. In addition it has been found that the pressure dependence of the freezing point of sea water implies that deep ice protrusions should melt, creating supercooled water which can then freeze on the bottom of thinner areas. The implications of this for the growth of ice sheets are being assessed through laboratory studies and theoretical calculations. (*Contact: D.R. Topham, E.L. Lewis.*)

Deep Sea

In September, an array of moorings carrying sediment traps, current meters and transmissometers was deployed near a known hydrothermal vent plume field on the Endeavour Ridge segment of the Juan de Fuca Ridge, in cooperation with the Geological Survey of Canada and Oregon State University. A CTD survey was conducted and water samples were collected. A towed body carrying a CTD and transmissometer detected the plume about 10 km from the ridge. These moorings are to be recovered in July of 1986. (*Contact: R.E. Thomson.*)

Three climate monitoring cruises to Ocean Station P (50°N, 145°W) were conducted in 1985. The data collected by the weatherships at this station between 1948 and 1981 were reviewed. Evidence of significant variations at depths as great as 3500 m was found, indicating responses of the overall circulation to variations in atmospheric fields. (*Contact: S. Tabata.*)

Experiments with various idealized basin-scale ocean models continued. The model developed by the Geophysical Fluid Dynamics Laboratory in the U.S. was obtained and installed on the Atmospheric Environment Service's (AES) Cray computer at Dorval. (*Contact: G. Holloway.*)

Forecasting

After numerical storm surge models indicated that the hypothetical "100 year storm" based on extrapolations of meteorological data would generate a surge which would flood most of Tuktoyaktuk, a survey of driftwood around the town was conducted in an attempt to gather better information on the actual incidence of extreme water levels. This is being extended to other areas in the Beaufort Sea, in cooperation with Environment Canada. (*Contact: R.F. Henry.*)

As part of a project sponsored by the World Meteorological Organization, a workshop on storm surges was organized in Bangladesh in December. The primary focus of the workshop was the importance of collecting reliable and quantitative observations of storm surges when they occur,

as such data is essential for the calibration of numerical models. Such models already exist, and could be used for predictions and warnings if accurately calibrated. The workshop was attended by meteorologists and coastal authorities from Bangladesh, Burma, Sri Lanka, Pakistan and Korea. (*Contact: R.F. Henry, T.S. Murty.*)

The effect of bottom roughness of deep ocean tsunami travel times was determined using a new theoretical model incorporating a statistical description of bottom topography. The potential response of Georgia Strait to local earthquakes was examined using the two km vertically integrated numerical model. (*Contact: G. Holloway, T.S. Murty.*)

In response to the recommendations of the inquiry into the loss of several fishing vessels in a storm on October 12-13, 1984, a number of activities designed to contribute to improved coastal weather and sea state forecasting were begun in cooperation with the Atmospheric Environment Service and the Canadian Coast Guard. These included a study of the impact of new observations on coastal sea-state forecasts, the continuation and up-grading of the coastal wave buoy network, and the groundwork for a new network of offshore meteorological buoys. (*Contact: J.F. Garrett.*)

Processes

A two-dimensional numerical model of the evolution of double diffusive instabilities was developed on a local contractor's VAX-730 array processor computer system. This permits calculations with a resolution greater than that readily achievable on much larger machines. The model is being used to study the interaction of double diffusive instabilities with velocity shears such as might be created by internal waves. Such work is essential to the eventual development of an accurate parameterization of small-scale processes for use in ocean circulation and climate models. (*Contact: G. Holloway.*)

Observational Techniques

The Fluorescence Line Imager (FL1) is a programmable multispectral imager developed by contracts with funding from DFO and the Interdepartmental Committee on Space. The prototype has been flown over land, lakes and the ocean, and has demonstrated that the performance objectives are achievable. In addition to the flight program, work this year has focussed on the analysis and interpretation of the

data collected and planning for demonstrations in Europe and China.
(Contact: J.F.R. Gower.)

A variety of acoustic remote sensing techniques for oceanic measurements are under investigation. Passive methods for determining wind speed and direction, precipitation, and ice strain by measuring sound levels in various frequency bands all show promise. Theoretical and experimental work is continuing in cooperation with the University of Victoria, various U.S. agencies and local contractors. These focus on the details of the sea surface processes which generate the noise. An observing system combining noise recordings with sea surface imagery obtained with both video and high frequency echo sounding was developed and tested for use in the FASINEX experiment, early in 1986. Development of an operational wind speed sensor for buoy use was begun. *(Contact: D.M. Farmer.)*

Several projects using back-scattered acoustic signals were also conducted. These include studies of the measurement of the vertical profile of sound speed (and hence temperature or salinity), correlation sonar measurements of ice and water motion, and measurements of the directional spectrum of ocean waves from a bottom mounted array. *(Contact: D.M. Farmer.)*

The most exciting acoustic development of 1985 was the demonstration that the scattering of acoustic signals transmitted across a tidal channel could be used to measure the flow in the channel. This has great potential for measurements in areas where conventional techniques are difficult, such as channels with very strong currents or active shipping. *(Contact: D.M. Farmer.)*

The small solar powered robot vessel known as the "Active Drifter", was tested at sea several times during the year. Its ability to maintain speed and heading in moderate sea conditions appears to be about the same as in smooth water, and the performance of the solar array is not adversely affected by motion and spray. The stresses associated with buoy motion in the wave field are large, however, resulting in a burnt-out motor on one trial. Tests are continuing, along with the commercial development of the station keeping buoy and experiments with a simple retrofit package for ordinary meteorological drifters. *(Contact: J.F. Garrett.)*

Computing Services



The principal activity during 1985 for Computing Services was the design and acquisition of a new computer. This will be added to the Central Computer Systems complex during 1986. Considerable attention was placed on designing the most cost-effective configuration for Phase I implementation and on plans for additional equipment and software for Phase II. This latter phase is scheduled for 1987-88. The final configuration for Phase I will be a VAX 785 processor with 16 MB main memory and floating point accelerator; 1.3 Gb disk storage; two 1600/6250 bpi tape drives; one laser printer, and three line printers. To complement this hardware, a number of programmer productivity aids were evaluated and specified during 1985, for inclusion in the VAX package. Among them were the full-screen editor, and a comprehensive graphics package which offered many new application-oriented features and extensive device support.

Design work during 1985 also included a tentative layout for an Ethernet local-area network to connect the new VAX processor with other VAX computers on-site. It is anticipated that this network will be installed during the Spring of 1986. The Gandalf PACX network for async devices continued to expand during the year, with the addition of new terminal and remote computer port connections. The network now supports a mixture of 84 terminals and personal computers, and 48 mainframe and minicomputer ports, including access to DATAPAC and BC tel dial lines.

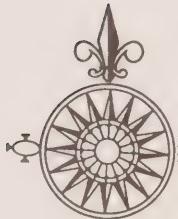
The Sperry mainframe continued to perform at full capacity during the year, with no changes to either hardware or system software. The NAG and IMSL numerical subroutine libraries, however, were upgraded during this time frame.

Computing Services also completed work on the HP flat-bed plotter support for the Sperry, and the design and initial implementation of the conversion of the IOS plotting software from the Sperry to the VAX.

By Spring of 1985, IOS access to the CRAY-1S at AES Dorval via DATAPAC got underway. After an initial learning period, much productive work was accomplished, leading to a peak utilization of 6.4 hours during October. Over the nine month period from April to December, two users clocked a total of 27 hours of CRAY time. The primary use of the CRAY supercomputer during 1985 was for large-scale ocean models to study climate and perform ice predictions. It is anticipated that the

requirement for this type of facility will increase significantly over the next few years, as more emphasis is placed on climate research, wave forecasting, and in joint programs with AES.

The acquisition of personal computer workstations for research, word processing, spreadsheet and database applications continued during 1985; 16 new PCs were added. Some of these systems were taken onboard ships for the first time, with considerable success. (*Contact: R.E. Johns.*)



Ocean Chemistry

Research was focussed on two major areas: the oceanic capacity to absorb CO₂ and other climatic gases, and to accept societal wastes of metals and petroleum pollutants. Pollution research addressed regional issues of disposal of mine tailings in Alice Arm, the dumping of contaminated sediment from False Creek (Vancouver) and the study of metal-binding proteins in coastal polychaetes compared to those in palm worms collected at hot vent sites. Ocean climate studies were concentrated on CO₂ through atmospheric monitoring in cooperation with Atmospheric Environment Service at Downsview; an extensive oceanic monitoring in the Pacific Ocean on the container carrier, *Lillooet*; IOS cruises to Ocean Station P (50°N 145°W) and CO₂ modelling. Related to the CO₂ removal process, an ocean flux program, in cooperation with Woods Hole Oceanographic Institution, using moored sediment traps, yielded a valuable time-series on fluxes of material, carbon, carbonate, nutrients and metals at Station P. Chemical tracers were applied to identification of both open-ocean and coastal-water masses and successes were evident for tritium, lead isotopic ratios and freons. Again in cooperation with Atmospheric Environment Service, a long-term study on background acidity of marine rain and aerosols, its distributions and causes, was initiated with the buildup of an acid-rain laboratory and shipboard program.

Funding by the International Development Research Centre (IDRC) made it possible for IOS scientists to conduct enclosure experiments in Xiamen, P.R. China and for Chinese scientists to participate in the SEAFLUXES enclosure work at IOS. Mr. Zheng Jiancheng has been our resident visiting scientist on CO₂ for the second year. Five other scientists, from the Third Oceanographic Institute, Xiamen University, Shandong College of Oceanology and the Dairen Institute of Marine Environmental

Protection, visited for terms of three months. U. Schwarz from the Department of Chemistry at the University of Victoria was completing her thesis study on freons at IOS. Additional projects were carried out with the University of Miami, Scripps Institution of Oceanography, Pacific Marine Environmental Laboratory of the National Oceanographic and Atmospheric Administration (NOAA), the Department of Oceanography at UBC and the Environmental Protection Service. Dr. G. Branton spent his sabbatical at IOS working on a cooperative fibre-optics study.

CO₂ and climatic gases are concerns that are global in nature, and research on the chemical aspects must be international in scope. These climatic studies will be carried out under various international programs, such as the World Climate Research Program and the Background Monitoring Network, which are in effect or being formulated by the Scientific Committee on Oceanic Research (SCOR), Committee on Climate Change and the Oceans (CCCO), World Meteorological Organization (WMO), International Council of Scientific Unions (ICSU) and Scientific Committee on Problems of the Environment (SCOPE).

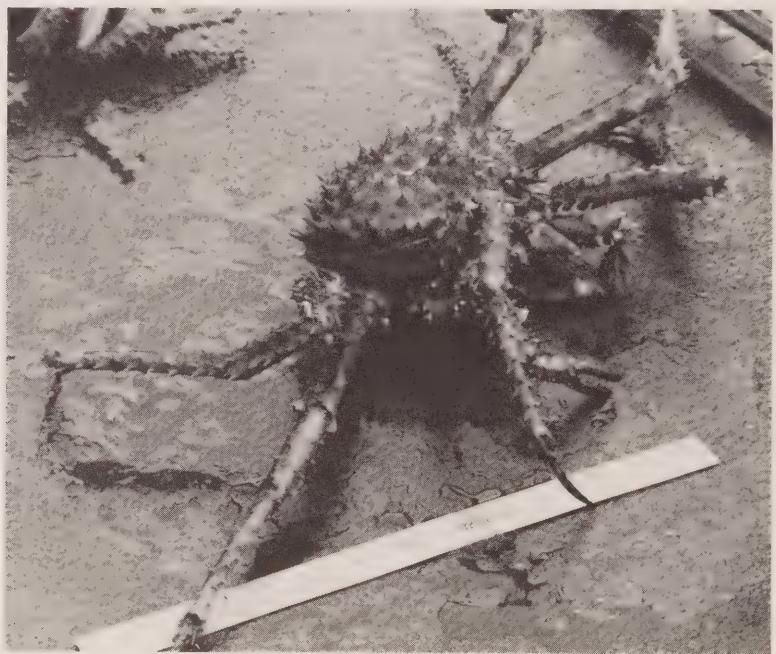
Pollution Research

Alice Arm

The study of mine tailings dumping in Alice Arm was in its final stage with publications and reports being written. Profiles of Pb-210 and metals in core samples, and sediment trap results indicated a strong effect of tailings dumping on the sedimentation rate, by as much as double, 8 km from the outfall. The study of nutrients and density of water movement suggested that convective replacement in the winter was the dominant process while in Observatory Inlet and Hastings Arm, downward diffusion renewed the two basins during the summer and early fall. (*Contact: R.W. Macdonald.*)

Trace metals in the water column were also utilized to identify water masses in the Alice Arm and Portland-Observatory Inlets. Using the clean room technique and mass spectrometric analysis, accurate levels of very low lead concentrations (ng or sub ng kg⁻¹), as well as cadmium and zinc, were obtained. Isotopic and concentration data of lead were used to identify water masses and sources: the major fluvial input, the mine tailings and deep, shelf waters. In particular, the deep, shelf waters with ultralow lead and less radiogenic isotopic ratio flowed in through Portland and Observatory Inlets to renew the bottom fjord water in Alice Arm. (*Contact: C.S. Wong.*)

Investigation of metal levels in the biota and pore waters following mine closure in 1982 were also continued into 1985. In cooperation with DFO's Habitat Management Division, a report on the metals and metal-binding proteins in the Golden King Crab, *Lithodes aequispina*, from the Alice Arm-Hastings Arm area has been completed. A study of the particulates in the gills of the crabs showed statistically an increase of lead burden in the gills of the specimens from the polluted Alice Arm, but undetectable in Hasting Arm samples. Examination by scanning electron microscopy (SEM) and energy dispersive X-ray (EDX), in cooperation with University of Victoria, indicated the absence of particles with high lead, molybdenum or zinc associated with sulfide minerals in the ore body. Particles that were silicones in nature were qualitatively identified as detrital clay. The work suggested the high lead burden to be intercellular and to be taken up through the gills in the dissolved phase. (*Contact: J.A.J. Thompson.*)



Golden King Crab, Lithodes aequispina, collected from the Alice Arm-Hastings Arm area, and found to have an increase of lead burden in the gills due to uptake from seawater.

Metal Binding Protein

A study of the metal binding protein in the nephtid polychaete from the tidal flats of Patricia Bay and the amphoretid polychaete, *Paralvinella palmiformis* (palm worm), a scarce species collected at hot vent sites in

1983-4, was conducted in cooperation with the Biology Department of University of Victoria. A polarographic technique was used to detect the metal-binding protein using the more abundant polychaetes from the tidal flats, then applying it to the scarcer palm worm. Arsenic, boron, zinc, copper, vanadium and cadmium were found to be within the levels found in other classes of marine biota. Studies of mucus excretions from the palm worms showed that uranium reached nearly 300 mg kg^{-1} in this material, suggesting its possible accumulation through absorption from the water column. Such studies on metal and protein were among the first being carried out on hydrothermal vent biota. (*Contact: J.A.J. Thompson.*)

Ocean Dumping

False Creek was the site of extensive dredging as part of the preparation for Expo 86. The sediments dredged from False Creek had high levels of cadmium (1.5 to $40 \mu\text{g g}^{-1}$) and of lead (200 - $800 \mu\text{g g}^{-1}$) and the flux of metals from sediment to sea water column was a matter of concern. Enclosure experiments were conducted to determine whether this flux could be reduced by covering the contaminated sediment with a layer of clean material (capping) at the disposal site.

A specially constructed catamaran barge with 1500 L polyethylene-lined fiberglass tanks was used to study the sea water-sediment interactions, metal release and capping with a clean alluvial material. The metal analysis was done by isotope dilution method using the unique clean room and mass spectrometer at IOS. The cadmium concentration of sea water in contact with the contaminated sediment or with the alluvial capping material (cadmium less than $0.3 \mu\text{g g}^{-1}$) doubled. When False Creek sediment was capped with the alluvial material, the concentration in the overlying seawater rose to four times its initial level. This work suggested capping to be ineffective for cadmium; the increase in cadmium in sea water could be accounted for by a release of only 0.06 per cent of the sediment-bound cadmium. Lead in this experiment behaved differently. The capping material did not release lead to the sea water, and appeared to reduce the release of lead from the contaminated sediment by about 50 per cent. The maximum lead release occurred during the first week of the experiment and could be accounted for by only 0.001 per cent of the sediment-bound lead.

A different enclosure experiment was conducted on a much larger scale: 15 cm of False Creek sediment in contact with 70,000 L of sea water. An entirely different metal behaviour was observed in the water column of

18 m compared to the shallow 1 m depth of the catamaran containers. A vertical concentration gradient for both cadmium and lead developed. The sea water maxima (600 ng kg⁻¹ for each metal) occurred at a depth of 13 m, due to the effects of adsorption closer to the sediment. Such investigations point to the rudimentary nature of our knowledge of metal dynamics in sediment/sea water interactions and the difficulties in formulating regulations based on scientific observations.
(Contact: C.S. Wong.)

Canada/China Cooperative Experiments

A series of marine ecosystems enclosure experiments (MEEE), funded partially by the IDRC, was carried out at Patricia Bay and in Xiamen, P.R. China, with the participation of IOS, the Department of Oceanography at UBC, the Third Oceanographic Institute, Amoy University at Xiamen and the Shandong College of Oceanology at Qingdao. A team of eight Canadian scientists joined their Chinese colleagues in May in an experiment using enclosures of plastic bags inside a large, shaded stone-walled pond in Xiamen. A clean laboratory was also constructed at the Third Institute for the metal analysis. The lab was supervised by a Chinese scientist trained at IOS through IDRC funding. Heavy metals (copper, cadmium, mercury, zinc and lead) and sediments from the discharge of a fertilizer plant in Xiamen were added to the enclosures. Chemical and biological events were followed for a month. From July to September, five Chinese scientists participated in an experiment at IOS using a specially-constructed catamaran barge, fitted with foam flotation blocks and fiberglass tanks measuring ½ m x 1 m. Release rates for metal (cadmium, copper, lead and zinc) and biological events were followed for sediment/sea water interactions under simulated conditions of (a) sea water in sunlight, (b) sea water/sediment in sunlight, (c) sea water/sediment with no sunlight, (d) sea water/sediment with high silt loading, and (e) sea water/sediment in an anoxic environment. False Creek sediments were used. Anoxicity and the presence of sulfide removed the metals effectively. The sea water in contact with the sediment doubled its cadmium level and increased the copper level by a factor of six during the 24 day period. *(Contact: C.S. Wong.)*

Hydrocarbons

The report of the international Baffin Island Oil Spill Experiment (BIOS) was completed with the chemistry section under the chairmanship of



The enclosure configuration at the 3rd Institute of Oceanography, Xiamen, China, conducted as part of an IDRC-funded China/Canada pollution experiment.

Walter Cretney of IOS. Laboratory methods were being updated for the upcoming NOGAP sampling program. (*Contact: W.J. Cretney.*)

Planning was undertaken for the Northern Oil and Gas Action Plan (NOGAP). A field program is planned for 1986-88 and coordination of the research will rest with Ocean Chemistry. (*Contact: R.W. MacDonald.*)

Climate Studies

CO₂, Climatic Gases

The Marine Carbon Research Centre at IOS, now in its seventh year, has shifted its focus from atmospheric CO₂ monitoring to oceanic CO₂ problems by conducting research, monitoring and modelling of CO₂ and the biogeochemical carbon cycles. The Centre participated in developing an international network by taking a lead role in conducting the third meeting of SCOR Working Group-75 on Oceanic CO₂ Methodology held at Les Houches, France in September. The meeting was attended by 15 SCOR-WG members and invited experts to review plans for a world-wide program to measure oceanic CO₂. In October inputs were provided to CCCO through participation as a member of its CO₂ Panel. The first

meeting at Woods Hole Oceanographic Institution produced the justification for a world carbon program for consideration as elements of major global programs such as the World Ocean Circulation Experiment (WOCE), Tropical Ocean and Global Atmosphere (TOGA), and the Global Ocean Flux Study (GOFS); currently in the planning stages.

The atmospheric CO₂ monitoring program as part of World Meteorological Organization (WMO) background network, was carried out as a joint effort with Atmospheric Environment Service (Downsview, Ontario). Air samples from Alert, Sable Island and Cape St. James were sent to IOS for analysis of seasonal changes and secular rise of CO₂ in the atmosphere. A unique CO₂ calibration laboratory, equipped with a Caltech cathetometer capable of pressure measurements to ± 0.002 mm in height in a room with temperature controlled to $\pm 0.01^\circ\text{C}$, was built as an alternate facility to the Scripps WMO Central Laboratory. The IOS laboratory will serve as the Canadian national standards laboratory for CO₂ measurements and also for the development of oceanic CO₂ standards for global ocean monitoring.

The oceanic CO₂ monitoring program was based on sampling from the *Lillooet*, a container carrier running between Brisbane in Australia, Noumea in New Caledonia and Richmond, B.C., and IOS quarterly cruises to Ocean Station P (50°N 145°W). Very large seasonal amplitudes in partial pressure of CO₂ (pCO₂) were observed in different oceanic regimes: the subarctic, sub-tropical and even the equatorial Pacific waters. Compared to published historical data from the late 1950s, the *Lillooet* data suggested a secular increase in pCO₂ in the equatorial Pacific Ocean of about 1 part per million per year. The monitoring effort will be intensified to observe the possible effect of an impending El Nino on the upwelling supply of CO₂-rich waters at the equator and their associated high pCO₂. The Station P observations of pCO₂ and other CO₂ parameters were conducted with the participation of Mr. Zheng Jiancheng, a visiting scientist from the Third Oceanographic Institute in Xiamen, P.R. China.
(Contact: C.S. Wong.)

Work on CO₂ modelling was done on both the atmospheric CO₂ and on the oceanic process of the "biological pump". The amplitudes of seasonal changes of atmospheric CO₂ at the Canadian WMO Stations at Ocean Station P, Sable Island and Alert were examined for evidence of biospheric uptake of CO₂. A "biological pump" model was constructed using Station P time-series and sediment trap data to examine the process of photosynthetic uptake of CO₂ by phytoplankton and the subsequent transfer of carbon between the upper and deep ocean by the sinking of both calcareous carbon (shells and bones) and organic carbon

(fecal pellets of salp and copepods) detritus. (*Contact: C.S. Wong.*)

Ocean Flux

Ocean Chemistry Division continued its extensive program on ocean flux of material in the N.E. Pacific Ocean to understand the biogeochemical cycle. Experiments were carried out, using moored sequential sediment traps in co-operation with Woods Hole Oceanographic Institution (for the third successive year) and also using free-floating systems as an in-house study. The cooperative IOS/Woods Hole project has yielded a valuable time-series of material flux data from 1000 m and 3800 m depths at Ocean Station P from September 1982 to the present. A peak occurred in 1982-83 with extraordinarily large quantities of material, mainly fecal pellets of salp and copepods, transferred from the surface to the deep ocean. Further time-series observations yielded relatively lower material inputs into the deep ocean, with quantities similar to other sediment trap studies. The 1982-83 peak amounted to 5-10 per cent of the historical productivity at Station P measured in the 1960s. To understand and to model the "biological pump", an additional program was initiated to fill in the knowledge gaps. The production of carbon in surface waters was measured to 100 m depth for seasonal C-14 uptake rates, using suspended bottle arrays, and the flux of material, including detritus carbon, carbonate and nutrient elements, was evaluated in the upper ocean between 0 and 1000 m using a string of free-floating sediment traps attached to a satellite-positioned ARGOS buoy. The free-floating traps were adrift for two to four days. The C-14 measurements, obtained by a metal-free method and other clean procedures, consistently yielded higher values by 50-100 per cent, than the historical data. Flux in the upper ocean, to 1000 m, was substantial, amounting to 10-20 per cent of the surface production. Because of decomposition of the detritus during *in situ* storage in the sediment traps for up to six months, experiments were conducted to quantify the oxidative loss of material.

(*Contact: C.S. Wong.*)

Acid Rain

As part of the long-range plan to contribute to the Long-Range Transport of Atmospheric Pollutants Program (LRTAP) and to the future Global Tropospheric Chemistry Program (GTCP), a co-operative study was initiated with Atmospheric Environment Service. An acid-rain research laboratory was established; analyzing pH of rain waters over the ocean, anion and cation compositions of rain water, sulfur compounds in marine air and sea water, and aerosol compositions, including lead

isotopes. Shipboard collection facilities for rain and aerosols were also set up in cooperation with the University of Rhode Island and the SEAREX program. (*Contact: C.S. Wong, G. McBean.*)

Chemical Tracers of Water Masses

In addition to lead and lead isotopic ratios as tracers of water masses, other studies were done, using tritium at Ocean Station P in cooperation with University of Miami and the Ocean Physics Division of IOS, and using freon-11 and freon-12 in cooperation with University of Victoria. The time-series of tritium since 1974 was examined with GEOSECS spatial maps pointing to the possible control of the vertical distribution of tritium by advection along isopycnals. (*Contact: A.E. Gargett, C.S. Wong, G. Ostlund.*)

A contaminant-free freon method was developed by a University of Victoria graduate student under supervision at IOS. An intercalibration was conducted on NOAA's *Discoverer* to compare the IOS techniques to those of the Pacific Marine Environmental Laboratory (PMEL), shown to be compatible on the NOAA February-March cruise from Seattle to Alaska. Freon profiles were obtained in April-May, August and October-November on IOS cruises, and showed that freons, through air-sea exchange, had penetrated the upper ocean in subarctic waters to about 400 m depth. (*Contact: C.S. Wong.*)

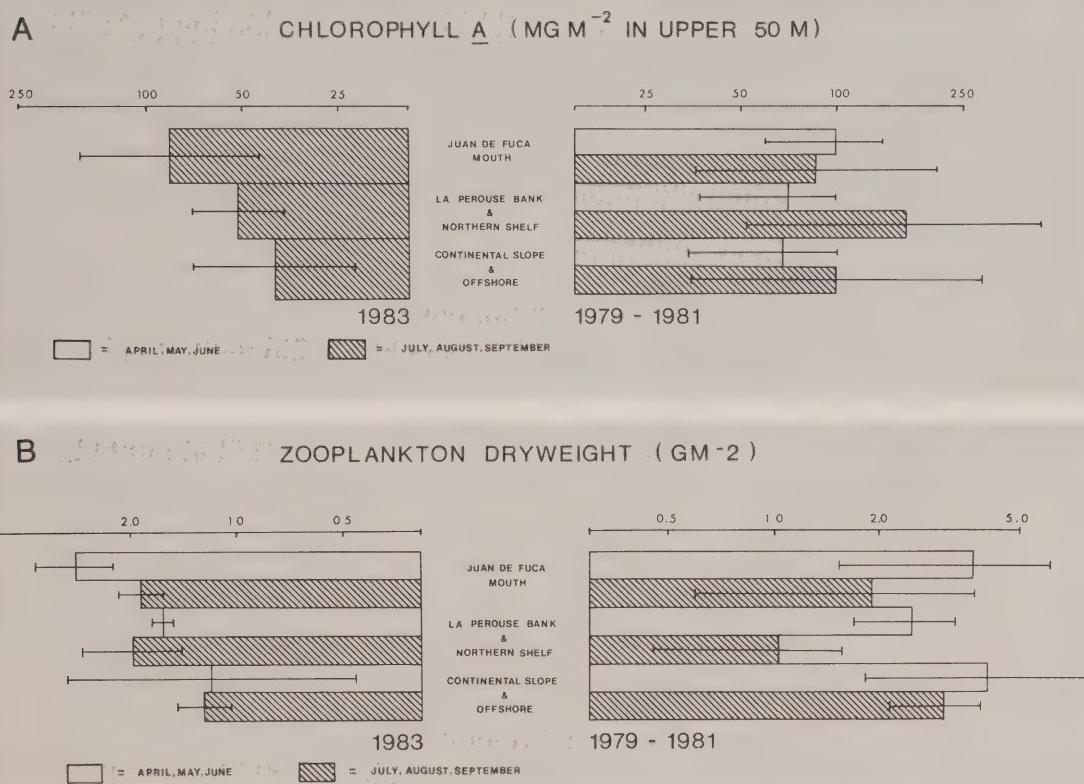


Ocean Ecology

Plankton

In 1985 the plankton group within Ocean Ecology concentrated its field effort on the continental shelf region adjacent to southwestern Vancouver Island. The impetus was the initiation of a long term cooperative project with the Pacific Biological Station, focussing on the herring and demersal fisheries on or near La Perouse Bank, offshore from Barkley Sound. The goals were to establish the links from physical processes through the planktonic food chain to the commercial fish stocks, and to resolve and understand interannual variabilities at these levels of the marine ecosystem.

The changes in plankton population occurring at a fixed location are the combined result of growth and mortality of the local population plus advective and migratory exchanges with surrounding populations. Previous observations show that peak zooplankton abundance on the southern Vancouver Island continental shelf typically occurs in early summer. The species composition changes, and total biomass declines, later in the summer, despite high concentrations of phytoplankton which are food for the herbivorous zooplankton. In June and July, 1985, the importance of advective removal of zooplankton from the continental shelf region was examined by tracing upper layer populations using drogued drifter buoys with internal LORAN positioning electronics.



A and B. Spring and summer seasonal average plankton biomass in three subregions of the Vancouver Island outer coast. Phytoplankton biomass (measured as chlorophyll concentration) is shown in top panel, zooplankton biomass (dryweight) in bottom panel. In normal years (1979-81), phytoplankton biomass is higher in the summer upwelling season (July-September) than in the spring (April-June), but summer zooplankton biomass is lower in the spring. In the summer following the 1982-83 El Nino, phytoplankton biomass was lower over most of the outer coast, but summer zooplankton biomass was reduced only in the offshore region.

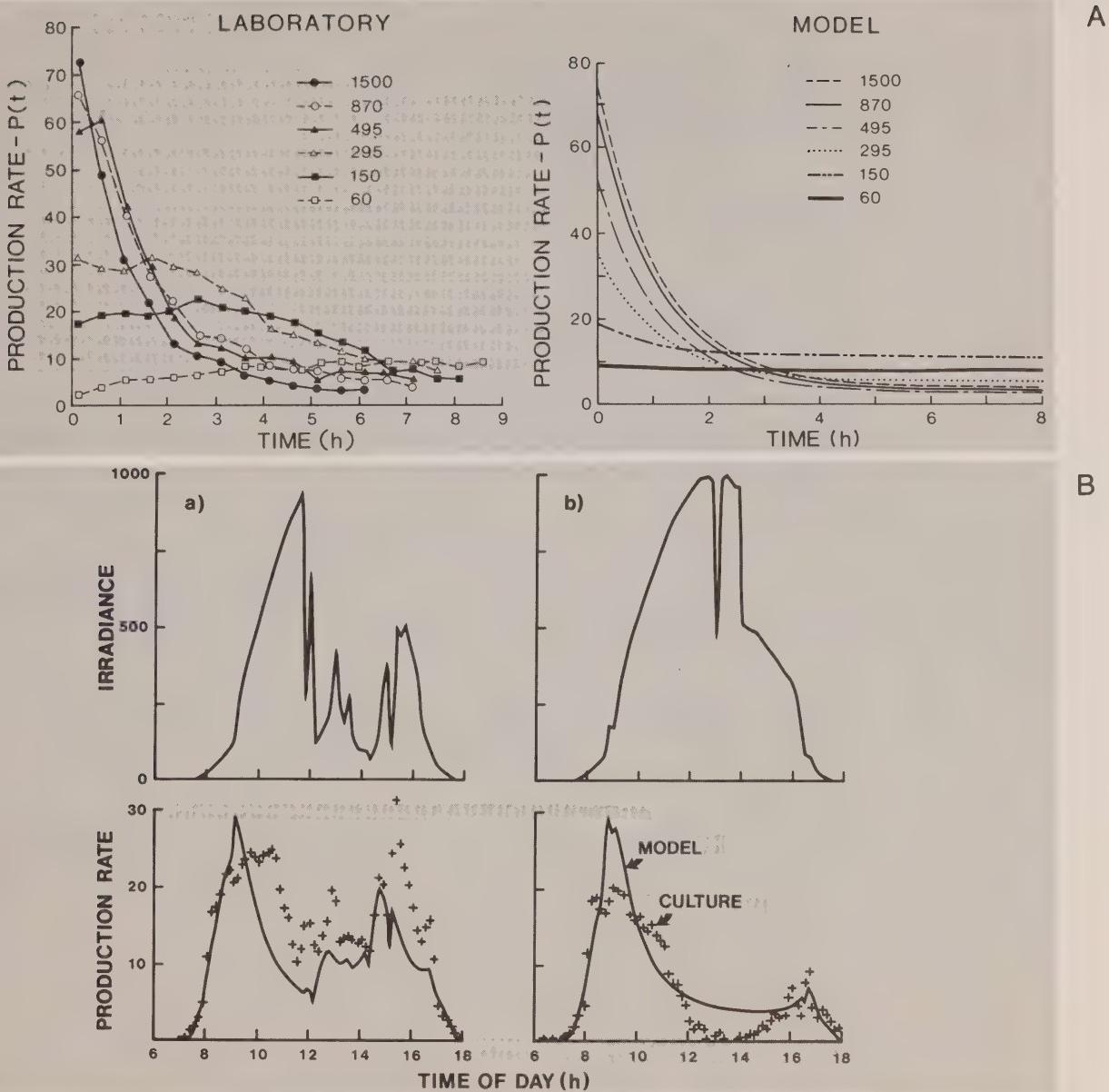
Drogues placed at midshelf moved seaward to the outer edge of the shelf and then south-southeast toward the Washington State coast. Average residence time on the B.C. shelf was only a few days. Replacement for the water advected seaward appears to be a mixture of deep upwelled water plus discharge from Juan de Fuca Strait. Both of these sources provide high concentrations of dissolved nutrients for phytoplankton growth, but tend to have low concentrations of the zooplankton species that form the normal spring population on the shelf. The advective flushing of the shelf (which appears to have been reduced in the El Nino year 1983) thus drives two competing processes: exporting biomass from the system, while enhancing the potential productivity of the organisms remaining. (*Contact: D. Mackas.*)

Field and laboratory experiments to resolve the spatial and temporal variability of daily cycles in phytoplankton productivity were continued. This work will be concluded in 1986. If the cycles are sufficiently predictable, the results will allow a re-analysis of previous spatial data to produce synoptic maps of productivity variables in British Columbia coastal waters.

An unusually large "red tide", extending from the mouth of Barkley Sound to south of the entrance to the Strait of Juan de Fuca, was encountered during a cruise in July. The opportunity was taken to map the distribution of biological and other water properties throughout the area, using a combination of underway sampling and vertical profiling equipment. Fortunately, similar measurements had been made in the area two weeks previously. Data will be analyzed to understand the preconditions that stimulate such a phytoplankton bloom.

Measurements of phytoplankton biomass and productivity, dissolved nutrients, and other water properties were made in Dixon Entrance and off the west coast of the Queen Charlotte Islands. These measurements will form baseline marine environmental data for the region, as little work of this type has been done here previously. The data will be useful for estimating fluxes into and out of Hecate Strait, which is of particular interest for its fish resources. (*Contact: R. Forbes.*)

Phytoplankton in the upper ocean experience short-term variations in light intensity for two reasons. First, changes in cloud cover and the daily cycle itself cause light variations, and second, various water motions move the plant cells vertically, in and out of the higher light levels near the sea surface. Many experiments have shown that the phytoplankton adapt or modify their photosynthetic capability physiologically in response to the light levels they have recently experienced. A model to



Model predictions for laboratory data obtained by Dr. John Marra of Columbia University. The upper diagrams (A) show constant irradiance at a variety of light intensities after the cells were conditioned in the dark for 12 hours. Figure B reflects two different days in a culture of phytoplankton grown under natural sunlight in a rooftop greenhouse. Also, for typical response times of 1–2 hours, the model predicts that vertical displacements caused by internal waves are too rapid to allow significant photoadaptation to occur except at the semidiurnal and diurnal tidal periods.

predict this time-dependent photoadaptation of phytoplankton to varying light levels has recently been completed. The model, based on linear response theory developed in power spectrum analysis, calculates the instantaneous rate of photosynthetic production based on a weighted integral of the light levels recently experienced by the phytoplankton cells. (*Contact: K. Denman.*)

Benthos

The major new initiative this year was the joint undertaking with the groundfish biology group of the Pacific Biological Station to study Hecate Strait. Four areas were intensively sampled on three occasions during the year, on joint cruises. The benthic data will not only contribute the information needed by fisheries scientists to compare with data derived from fish stomach analyses, but will also provide a detailed account of seasonal changes of the relative abundance of species and changes in biomass.

This study took precedence over the study of recolonization of mine tailings in Alice Arm, which was also delayed owing to cancellation of a joint cruise in the fall of 1985. Samples are being obtained by Amax of Canada Limited and there is some prospect of reactivating the work in 1986.

The study of samples from Boundary Bay, stimulated by the suggestion of a connection between a PCB spill in a tributary stream and an apparent increase in mortality of grey whales, progressed to the point of identification of the samples to major groups. These show a diverse fauna at nearly all stations sampled and no basis for immediate concern. The detailed identification of species is now being pursued so as to provide a quantitative description of the macrobenthos of an area quite susceptible to environmental impact.

The study of the benthos of the continental shelf is slowly reaching the reporting stage. The bulk of the species identifications and verifications has been completed, and all the primary tables corrected and condensed for publication. It seems as though differences in substrate have sufficient impact on the fauna that the influence of other variables will be difficult to discern despite attempts to minimize the variability of substrates sampled. (*Contact: R.O. Brinkhurst.*)

Taxonomic studies on oligochaetes were continued, and as usual a considerable amount of support was provided on a worldwide basis to applied biologists who supplied material for identification or verification,

solicited information and advice, or sent manuscripts for review. A second trip to Lake Titicaca and the Amazon River in Peru was most successful in that this time some of the most significant but poorly described South American species were re-discovered. A detailed account of South American species will result. A new identification manual for industry and government biologists in North America was completed and published. The two-part review of the complex estuarine genus *Tubificoides* was published. Courses in identification were run for the Tennessee Valley Authority, Carolina Power and Light and the British Estuarine group. A revision of evolutionary and comparative methods in systematics was completed and is now in the review process. An experimental study supported the hypothesis that hair setae can be reduced or absent in specimens obtained from areas of high conductivity in the water, or at the inner end of estuaries. (*Contact: R.O. Brinkhurst.*)

Two post-doctoral fellows, A.F. Nemec and S.K. Juniper, completed their terms with us and were replaced by Y. Simard and (via the University of Victoria) K. Wong.

Numerical Taxonomy

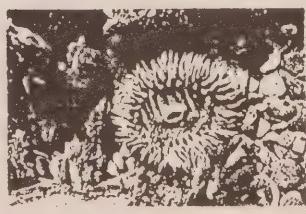
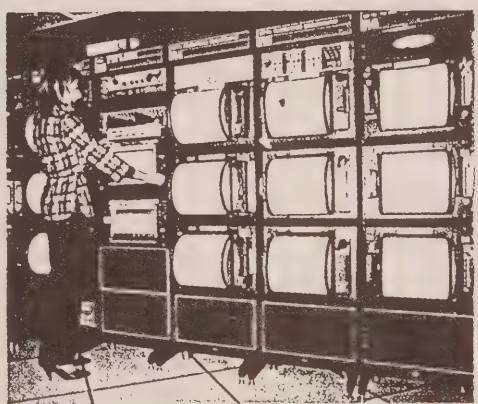
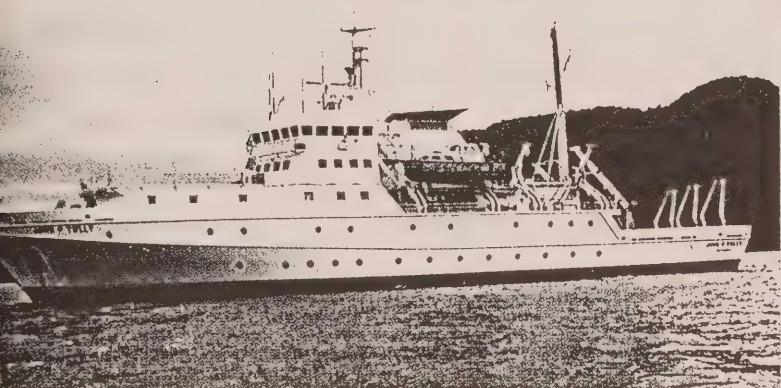
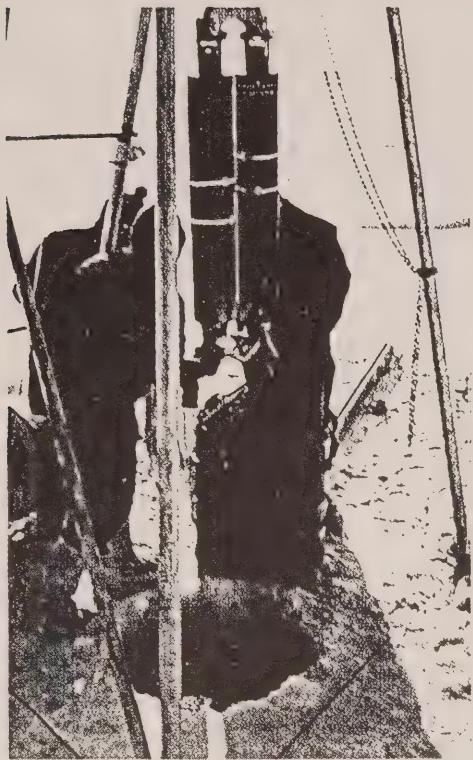
A number of different numerical techniques, including cluster analysis, character compatibility analysis, and the method of parsimony, were used to investigate the evolutionary relationships that exist among 23 species of the oligochaete family, Naididae. The classification of the Naididae was then reviewed and a revised classification, based on the results of the analyses, was proposed. In addition, the relative performance of the numerical methods was assessed subjectively and according to several objective criteria. The conclusions drawn from this and similar studies not only enhance our understanding of evolutionary processes, but also lead to greater proficiency in organizing and interpreting what are often very large data sets. (*Contact: A.F.L. Nemec.*)

Time Series Analysis

Time series analysis has many applications in oceanography, as well as other fields as diverse as astronomy, economics and medicine. One example of an oceanographic application is the analysis of temperature measurements of a hot vent, which is currently underway (with Kim Juniper). The outcome of this analysis should provide useful information regarding the physical conditions to which the biological communities of hot vents are subjected. (*Contact: A.F.L. Nemec.*)

The search for periodicities is an important aspect of time series analysis, since periods (wavelengths, in the case of spatial data) often have significant physical interpretations. The analysis of observations that are not uniformly spaced presents special problems. Although there are a number of ad hoc techniques ("phase dispersion minimization methods") that are used to estimate periods when the data are unequally spaced, little is known about the statistical properties of these methods. In particular, there is no objective way of assessing the statistical significance of period estimates. In response to this limitation, a randomization test was developed. (*Contact: A.F.L. Nemeč.*)

Ocean Information



Ocean Information



The Ocean Information Division provides information about IOS programs to specialized clients, the media and the general public; it also oversees a program to provide a long-term record of coastal sea surface properties in B.C. The information given out must match the needs and capabilities of the recipient, and the Division's products consequently vary from general letters and brochures about oceanography or hydrography to quite technical publications and advice.

The demand for data by clients outside the oceanographic community appears to be increasing. Prominent among the groups requesting information is the growing aquaculture industry on the west coast, for which information about the temperature, salinity, nutrients and circulation is an important factor in deciding where to locate.

Among the Division's specialized clients are the regulatory and advisory bodies concerned with protecting marine environmental quality. In 1985, we closed the book on our involvement with the federal environmental Panel for hydrocarbon development in the Beaufort Sea and opened a new one for hydrocarbon exploration off the West Coast. The IOS contribution to the federal-provincial Panel hearings into proposed drilling in Hecate Strait, Dixon Entrance and Queen Charlotte Sound was one of the most demanding of our advisory tasks during the year.

Climatology



The B.C. Shorestation Oceanographic Program obtained daily surface (one-metre depth) seawater salinity and/or temperature measurements at 16 locations in 1985. In addition, the 1984 data were published.

Preliminary examination of the 1985 data suggests that the values of surface salinity recorded at each site exhibited no significant departure from long-term values. The same characteristics appeared to describe the corresponding temperatures for the first 10 months of the year. However, during November and December, there was an abrupt lessening of temperature along the coast generally. The cooling was basically defined by anomalies greater than about 1.5 standard deviations from the long-term monthly means for the seven stations with 45 or more years of data.

The changes in anomaly were abrupt both with time and in magnitude. Anomalies of between 1.5 and 2 standard deviations occurred at all "open-ocean" stations (e.g. Langara Island and Amphitrite Point) for one or both of these months. By far the largest anomalies—more than three standard deviations—were recorded in the Race Rocks area, a somewhat more sheltered location than the open-ocean sites. They were the greatest ever recorded at this location. Surface waters of the Strait of Georgia—the area most protected from "outside" marine influence—were also markedly colder, as indicated by the anomaly of almost two standard deviations registered at Entrance Island, the only long-term station reporting in the Strait in 1985. The presence of this effect tended to be borne out by other, shorter-term, records obtained in the Strait. Among the coldest seawater temperatures ever recorded in the program were those found at the beginning of December at the West Vancouver site (1.5 to 1.9°C). For comparison, it may be noted that positive "warming" anomalies of between two and three standard deviations were fairly common at the outside coast during the major El Nino event in 1982-83. The markedly cooler surface waters of late 1985 were presumably an oceanographic manifestation of the extremely severe weather conditions on the B.C. coast during November and December. (*Contact: L.F. Giovando.*)



Environmental Advisory Services

During 1985, Ocean Information Division coordinated the oceanographic component of DFO's involvement in the West Coast Offshore Exploration and Environmental Assessment Panel. The Division's work comprised several tasks, including: the provision, to the federal-provincial Panel, of a large amount of information required during the course of the hearing; attendance (with other Institute personnel) at major public hearings at Prince Rupert, Vancouver and Victoria in October; and contribution to the submission dealing with DFO's position and recommendations on the proposed exploration for hydrocarbons. Release of the Panel's report is expected in early 1986. (*Contact: L.F. Giovando.*)

The Division continued to be the focus of the Institute's support to two (Pacific and western Arctic) regional ocean dumping advisory committees (RODAC). Contributions were tendered toward the approval of about 50 applications and to several formal reviews. The most difficult subject

dealt with during the year comprised two applications for the disposal of substandard or waste gypsum wallboard.

Participation on the Arctic Waters Advisory Committee (AWAC) required the provision of oceanographic advice and information on diverse issues of safety and environmental protection arising from applications by offshore industries. Although offshore activity in the oil and gas sector appears to be scaling down somewhat in Canadian waters, 1985 was relatively busy in the Beaufort Sea and Sverdrup Basin regions. For example, drilling approvals for Gulf, Esso, Dome, Chevron and Panarctic necessitated the governments' setting of environmental operating conditions, including physical and environmental monitoring programs, for about 20 wells. In addition, 10 dredging leases and applications for island and harbour construction were reviewed for their technical and environmental soundness. (*Contact: B.D. Smiley.*)

IOS contributed to a major industry-government effort to formulate a code of practice for the future use of oil-based muds in Arctic waters. Oil-based muds are preferred in some applications to prevent the rotating drill pipe from sticking. However, their use poses an increased environmental risk to marine life when discharged into the ocean.

Several companies improved and updated their oilspill contingency plans during the year. One such plan was suddenly tested on September 17 when about 450 tonnes of diesel oil was released into the Beaufort Sea, 10 km off the mouth of the Mackenzie River delta. The spill occurred when the Esso Resources artificial island, made of sand and gravel, was damaged extensively during the worst summer storm recorded in the region. With winds of 50-55 knots, and estimated four-metre waves breaking on the beach, about one-half the island's working surface eroded into the sea, taking with it the drill rig, a three-storey modular camp and one of four diesel storage tanks. The resulting diesel oil slick floated for about three days before dispersing. Throughout the spill event, IOS scientists provided oceanographic advice to the Canadian Oil and Gas Lands Administration (COGLA) in Yellowknife on the fate and behaviour of oilspills on the ocean surface. (*Contact: R.C.H. Wilson.*)

Information Management

For several years, the Division has produced a series of inventory reports to facilitate access to oceanographic data in the Arctic. In 1985, the first



steps were taken to make this now substantial body of data available to external users by means of a computer on an interactive database. When it is offered to users in 1986, this service will greatly facilitate the search for accumulated physical, chemical and biological data of the western Arctic.

Called the Arctic Data Cataloguing and Appraisal Program (ADCAP), detailed information about collection techniques and procedures, storage and analysis, together with measurement quality ratings and data services, allow users to gain an impression of the completeness, reliability and accessibility of these data.

To date, seven inventories, averaging 300 pages, of historical overviews, tables, station maps, location indexes, references and sources have been published. In 1985, contractual work on several new catalogues continued, e.g. Beaufort Sea whales, zoobenthos and fishes, and Northwest Passage fishes and zoobenthos; and four more—Beaufort Sea whales, Beaufort Sea plankton, Northwest Passage whales, and Queen Elizabeth Islands chemistry—were started.

An opinion poll to assess the effectiveness of ADCAP, conducted in 1985, indicated that the majority considered the catalogues quite useful as reference tools (to varying degrees) for wide ranging purposes, from research planning to engineering design or impact assessment. (*Contact: B.D. Smiley.*)

An initiative analogous to ADCAP—the West Coast Data Inventory and Appraisal Program—has been commenced for the Pacific Ocean off Canada. For convenience, and also by analogy, the program title has been designated as WESCAP. To date, two inventories—both dealing with physics—have been published: that for Dixon Entrance-Hecate Strait-Queen Charlotte Sound, and that for offshore waters out to the Canadian 200-mile fishing limit. Corresponding inventories for chemistry are nearing completion. The emphasis that has been initially placed on waters north of Vancouver Island has resulted from requirements perceived as ensuing from the proposal to explore for hydrocarbon in these waters.

For purposes of regional planning, impact assessment, research investigations and regulatory guidance, a complete record of some major Arctic industrial activities associated with the oil and gas sector is also being compiled. The first volume describes the more than 100 marine dredging operations that took place in the Beaufort Sea from 1959 to 1982. The second volume covers offshore seismic surveys in the Sverdrup Basin area from 1974 to 1984. A third publication, dealing with drill waste

discharges, is in preparation. (*Contact: B.D. Smiley.*)

Public Information

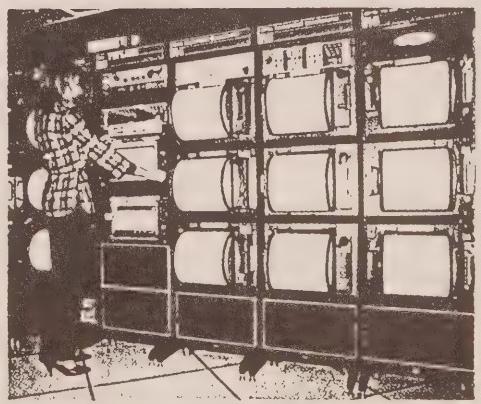
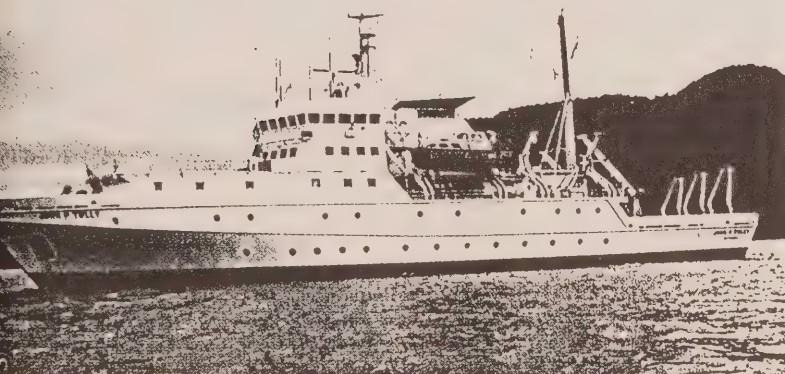
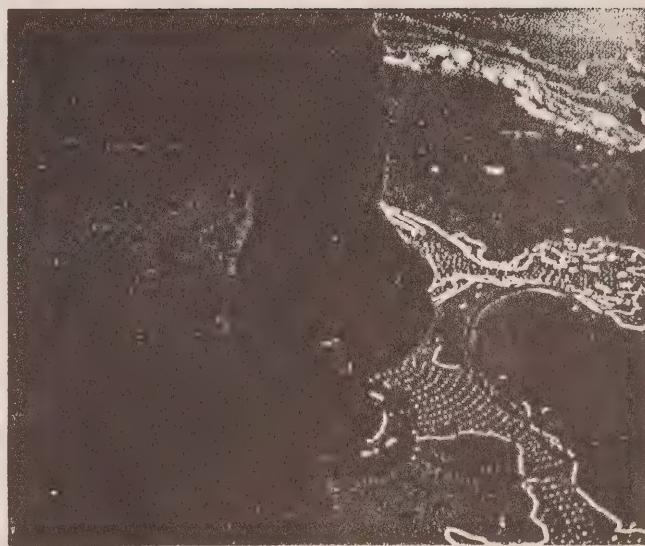
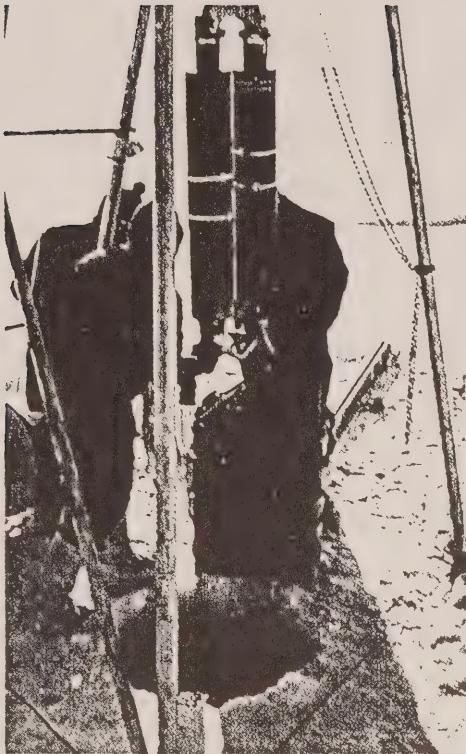


The Division sponsored a project, under the auspices of International Youth Year, to improve the resource material for the public tour program at IOS. A group of young professionals designed and produced a number of static displays and completely revamped the Institute's multi-image slide show.

The fourth in the new series of IOS Annual Reviews was prepared as were contributions to other government and non-government publications. The IOS Report, produced monthly, was continued and distribution increased to include various client and user groups.

Advice and materials were provided to the Pacific National Exhibition for the feature exhibit—Hidden Faces of the Sea—at the 1985 fair. An estimated 1.2 million visitors, the second highest in history, attended. (*Contact: K. Glover.*)

Ships





Ships

Ship Division continued to provide ship, launch, submersible and workshop support for the scientific and hydrographic programs of the Institute of Ocean Sciences (IOS), the Pacific Geoscience Centre (PGC), universities and other federal agencies in 1985.

Of major importance was the official acceptance of the CSS *John P. Tully* in the early summer. After commissioning, the ship commenced service in the western Arctic.

The year also saw the charter vessel MV *Pandora II* and the submersible *Pisces IV* working out of the Bedford Institute of Oceanography on the Atlantic coast.

CSS *JOHN P. TULLY* (69 m overall; gross tonnage 2199)

Master: B.L. Newton *Chief Engineer:* P. Pereira

After delivery from Bel-Aire Shipyard Ltd. on June 4, a month was spent by the captain and crew familiarizing themselves with the new ship. A commissioning ceremony was held on June 22 at the Institute of Ocean Sciences.

On July 10, the CSS *John P. Tully* departed for the Beaufort Sea for hydrographic survey of the Herschel Island and Kugmallit Bay areas, and a geophysical survey, conducted by Energy, Mines and Resources, between Herschel Island and the international boundary. The ship arrived back at IOS in early October.

During October and November, the CSS *John P. Tully* was used off the B.C. and Washington coasts by all three IOS oceanographic divisions.

In December, the ship was returned to the shipyard for routine warranty work, which, despite the heavy ice conditions encountered on her maiden voyage, was not serious.

CSS *PARIZEAU* (64.6 m overall; gross tonnage 1314)

Master: A.G. Chamberlain *Chief Engineer:* G. Winterburn

The CSS *Parizeau* provided support for the Pacific Geoscience Centre, the Department of National Defence (DND) and Canadian universities in

addition to working with Ocean Physics Division, Tidal and Current Surveys and Ocean Chemistry Division. As has become customary, the CSS *Parizeau* acted as a Search and Rescue vessel for the herring roe fleet.

CSS *VECTOR* (39.6 m overall; gross tonnage 516)

Master: R.W. MacKenzie

Chief Engineer: R. Pearson

Support was provided by the *Vector* to programs for Ocean Physics Division, Ocean Chemistry Division, University of British Columbia, Simon Fraser University, Tidal and Current Surveys, Environmental Protection Service and Pacific Geoscience Centre. A two-week cruise was also undertaken for Royal Roads Military College.

CSS *RICHARDSON* (19.8 m overall; gross tonnage 59)

Master: J. LeGarff

Most of the season was spent supporting the Hydrographic Division conducting surveys in the Queen Charlotte Islands area. The *Richardson* was also used as a Search and Rescue vessel during the 1985 herring roe fishery.

MV *PANDORA II*, on charter (58.2 m overall; gross tonnage 1378)

Master: S. Gulati

Chief Engineer: R. Rogers

The *Pandora II* was employed for most of the 1985 field season on the Atlantic coast, acting as the mothership for the *Pisces IV* submersible and providing support for scientific activities being carried out by the staff of the Bedford Institute of Oceanography and the Atlantic Geoscience Centre.

PISCES IV (6.1 m overall; gross tonnage 12)

Chief Pilot: F. Chambers

In preparation for east coast deployment, *Pisces* underwent an extensive maintenance period. The submersible completed a two-week operation off the west coast for DND in conjunction with the U.S. Navy, then headed east onboard *Pandora II*. While based on Canada's east coast in 1985, *Pisces IV* was utilized by Bedford Institute and Atlantic Geoscience

Centre scientists to conduct 14 major cruises, some above 70° north. The two most significant operations were the discovery of natural oil seeps off Scott Inlet and the recovery of two current meters lost in 1983 due to release failures. *Pisces IV* returned to IOS on December 4 onboard the MV *Pandora II*.

BARGE PENDER

During 1985, the barge was mainly used by the Hydrographic Division. In April and May, surveys were conducted in the False Creek area of Vancouver, in connection with Expo 86. From June through September, the *Pender* operated in the Tofino area. Ocean Physics Division used the barge in local waters during November for echometer experiments.

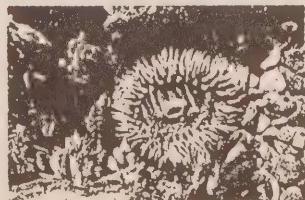
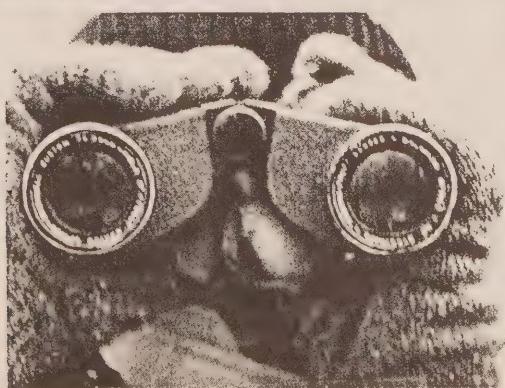
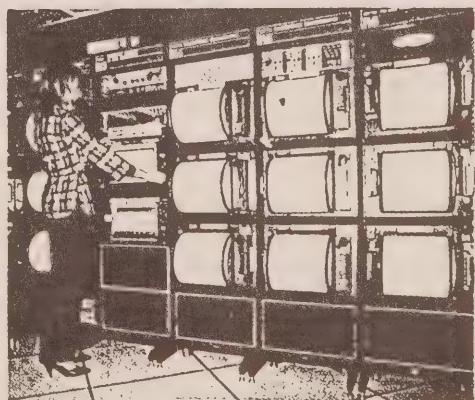
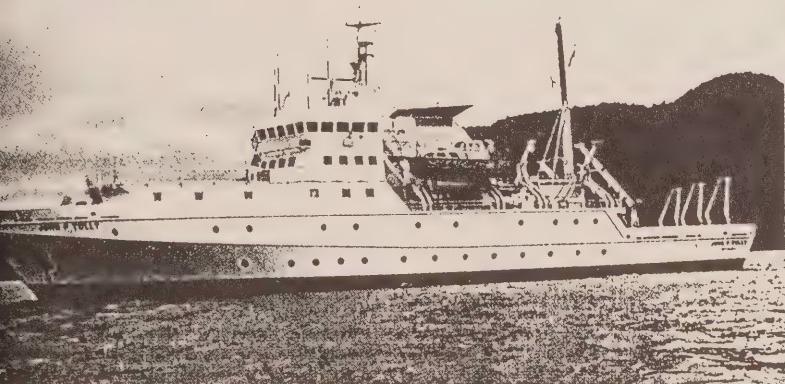
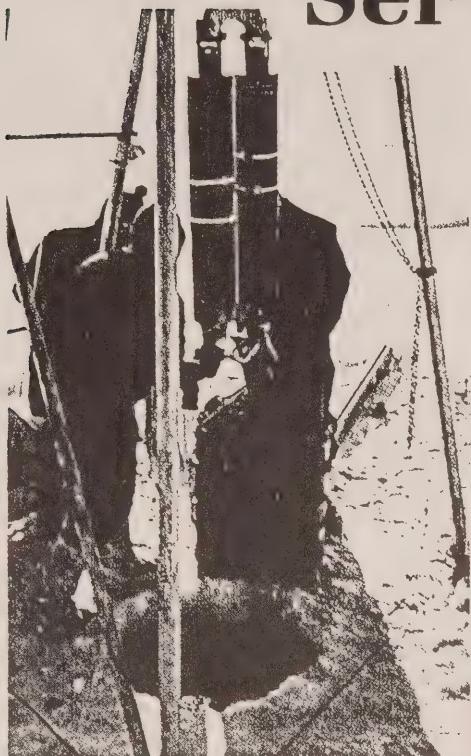
Institute Workshops

The depot staff were responsible for construction, repair and maintenance of the Institute's fleet of launches and small boats, as well as providing mechanical support for the *Pender*, CSS *John P. Tully* and CSS *Richardson*. Workshop staff also rebuilt the three diesel engines on the CSS *Vector* and one other diesel motor. Over 400 work orders were completed for various IOS divisions.

Deck Machinery

Staff continued to maintain and service winches and associated equipment in use on the IOS fleet. During 1985 considerable effort went into fitting winches, etc. to the new CSS *John P. Tully*.

Management Services





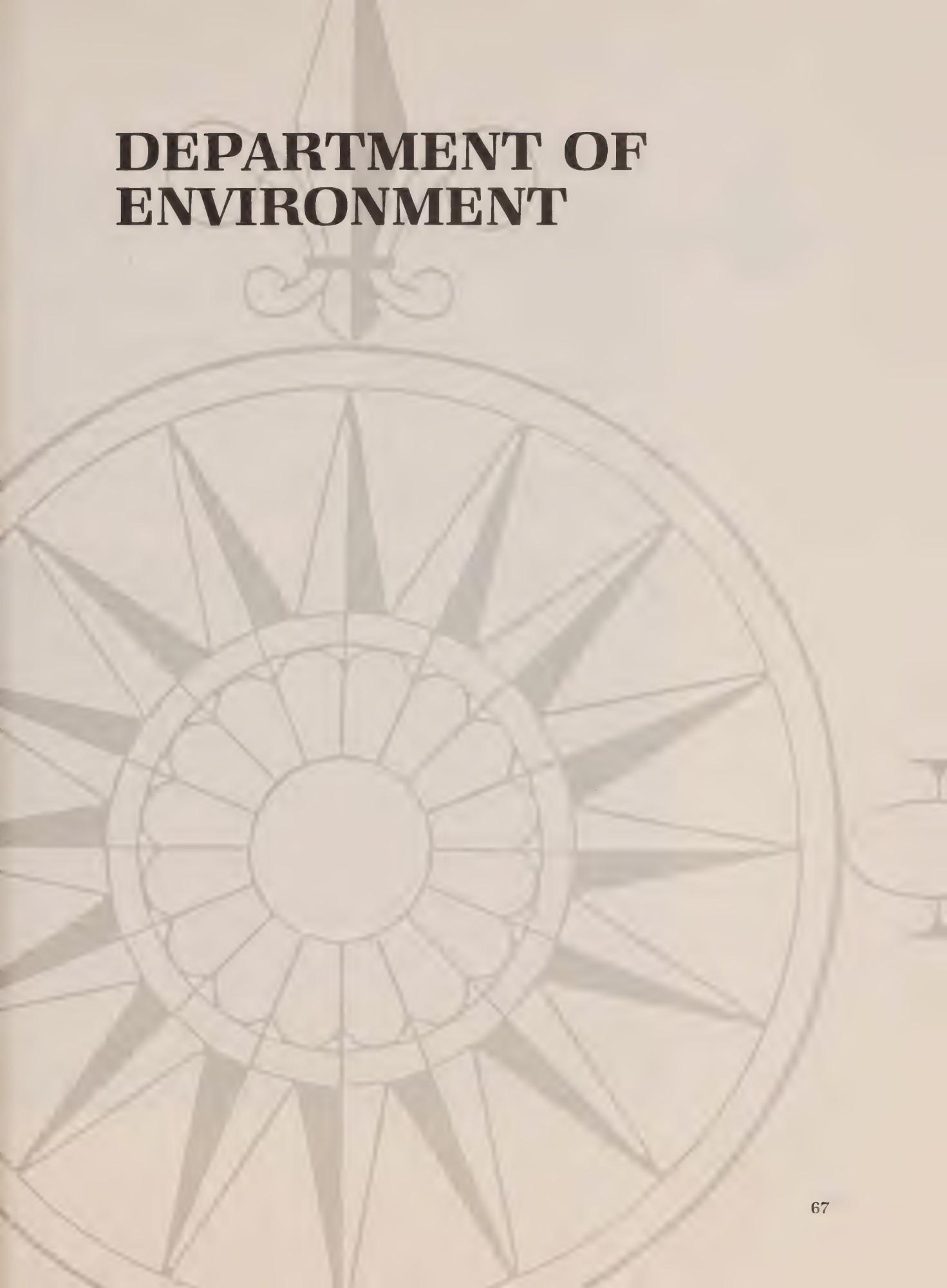
Management Services

With the commissioning of the CSS *John P. Tully* in 1985, the overall workload in Management Services has increased by approximately 10%. This increase was absorbed through productivity, the use of several term positions and temporary help agencies. Very little progress has yet been made in the development of a departmental central financial system, which still leaves IOS line managers relying on an out-dated system for financial information.

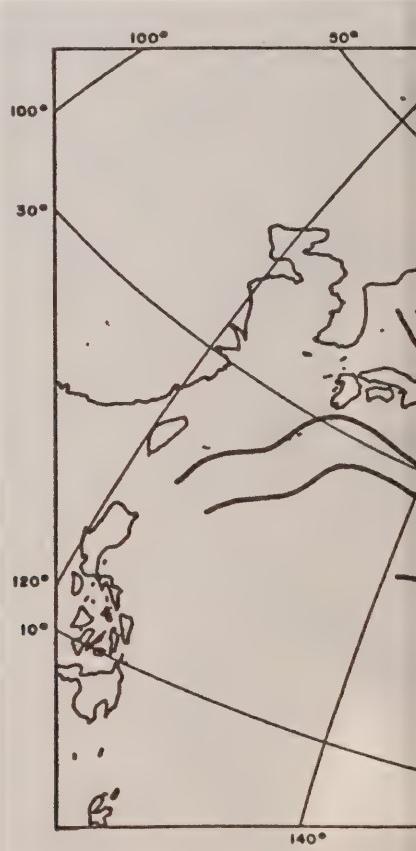
One job development program (FRED) came to an end in 1985 and another began. DFO is jointly administering \$15 million worth (85-86) of job development programs with Employment and Immigration Canada (EIC). At IOS, 14 projects creating 78 jobs and with a total value of \$1.39 million currently have been approved by EIC. The intent of this program is to provide training and work experience primarily in the private-sector marine science and technology industries.

Several significant projects were undertaken by Management Services in 1985. Among these were: the purchase and installation of an uninterrupted power supply for automated cartography; essential repairs to the IOS wharf; and, modifications to offices and labs. In addition, Management Services personnel participated in the development and presentation of training materials in the areas of purchasing and finance, as part of a middle management orientation course.

DEPARTMENT OF ENVIRONMENT



The 30-year average of the total amount of heat transferred from the ocean to the atmosphere over the North Pacific Ocean. (Units are watts per square metre.) Notice the maximum heat transfer just east of Japan over the Kuroshio Current system.

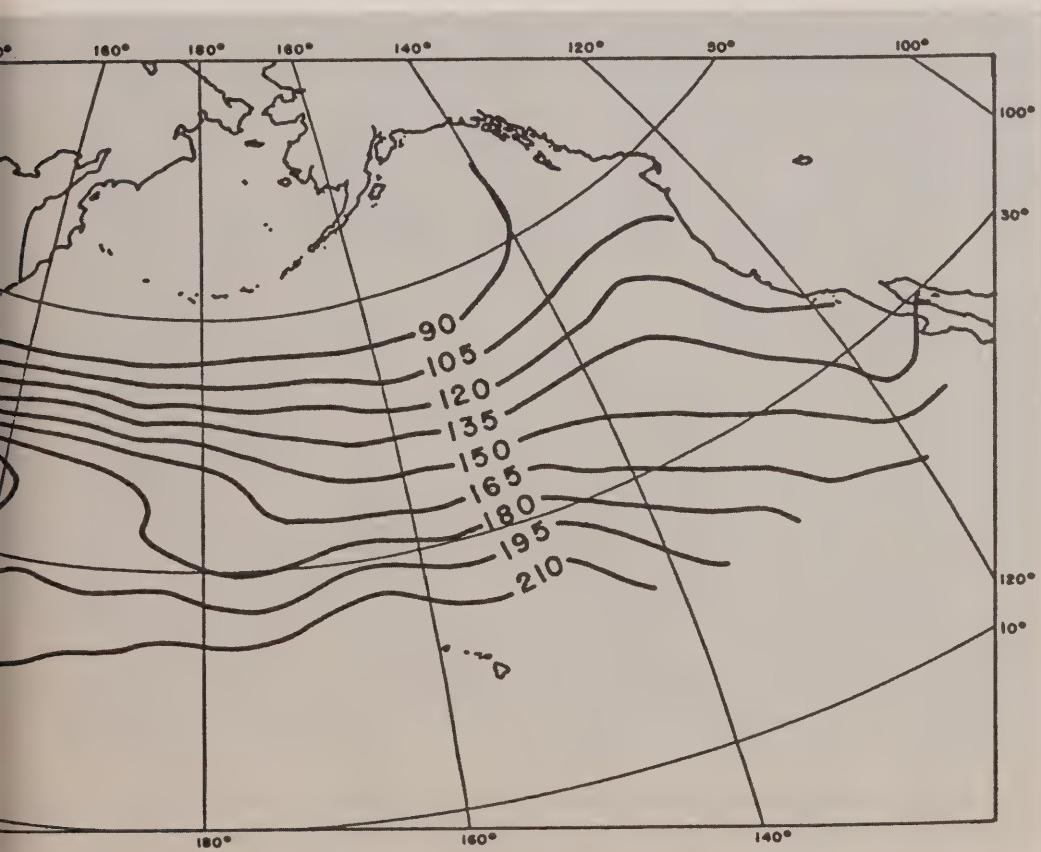


Atmospheric Environment Service— Canadian Climate Centre



Atmosphere-Ocean Interactions

The heat transferred from the ocean to the atmosphere plays a major role in determining the evolution of the atmospheric climate. The atmosphere has a relatively short memory (days to weeks) so it is unlikely that predictions of seasonal or longer period climate changes can be based on atmospheric information alone. On the other hand, the oceans have a relatively long memory time (ranging from months to decades) depending on the depth of the ocean considered, and it is hoped that this information will enable much longer climate predictions. During the past year the variability of the total amount of heat transferred from the

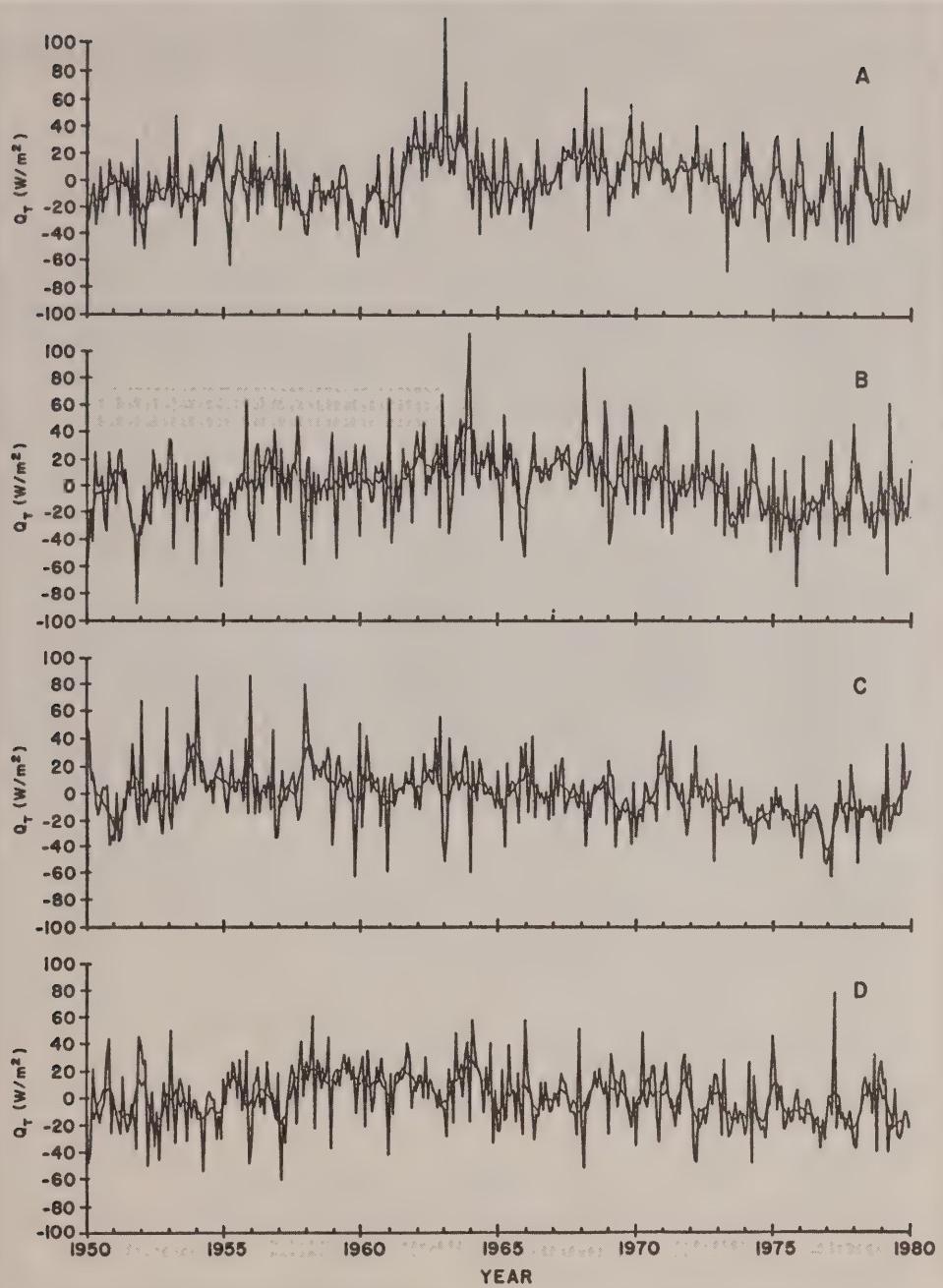


ocean to the atmosphere over the north Pacific Ocean has been investigated. This work is being done in cooperation with Y.P. Zhao, a visiting scientist from the Institute of Oceanography, Academia Sinica, China.

It was first found that the annual cycle of total ocean to atmosphere heat transfer varied in different regions of the ocean. On the west side of the ocean, the Asian monsoonal circulation played a major role while, to the east, the variations of storminess, and the annual cycle of sea surface temperature, dominated. The variations from this annual cycle—the interannual variations—also differed across the ocean basin. The heat transfers were spatially correlated over the Kuroshio current system, but not with the heat transfers over the eastern two-thirds of the basin. From the Alaska and California current areas heat transfers were highly correlated. In the winter time there is a tendency for the anomalies of heat transfer to be of opposite signs over the eastern and western sides of the ocean. Looking at the basin as a whole, the anomalies of heat transfer since 1973 have generally been negative while in the 1960's they were generally positive. In 1962-63 there was a marked positive anomaly over the western part of the basin. It is important to understand the reasons for these major anomalies as they present the possibility of a basis for future prediction techniques.

The relationship between the ocean-to-atmosphere heat transfer anomalies and the anomalies of the atmospheric circulation, as represented by the sea level pressure and 700mb height fields, was then investigated. As expected, the anomalies in the heat transfer had a large local impact in the winter. Greater amounts of heat from the ocean were related to a deeper Aleutian low pressure system which also tended to move to the southwest. The pressures both immediately upstream and downstream of the Kuroshio area were also affected. In the summer, there was no significant local correlation, but there was an interesting correlation between heating over the mid-Pacific Ocean and the 700mb height anomalies over the Tibetan Plateau. This can be explained in terms of a zonal-vertical circulation pattern that is established downstream of the Plateau, which typically has a 700mb pressure as its surface pressure. It appears that the explanation for both these phenomena is one of the atmosphere affecting the ocean-to-atmosphere heat transfer, rather than the other way around. This will be investigated further.

Of particular interest for climate prediction are the correlations found between the heat transfer to the atmosphere over the Kuroshio in the winter, and the sea level pressure patterns the following summer over



Time series of the anomalies of total heat transfer from four characteristic areas of the North Pacific Ocean: A) the Kuroshio; B) the central North Pacific; C) the Gulf of Alaska; and, D) the California Current.

eastern North America and the following winter over Europe. A mechanism to explain these correlations is being sought. Some cooperative modelling work being done by L. Mysak and his students will help in this regard. (*Contact: G.A. McBean.*)

Intercomparisons of Atmospheric Sounding Systems

Two studies have been completed, in cooperation with D.J. Phillips and J.R. Mathieson of AES, Pacific Region, to compare atmospheric sounding systems. During the Storm Transfer and Response Experiment (STREX), upper-air balloons were tracked by radar on the Weather Ship and by navigation signals (Navaid). The winds deduced from these systems were found to compare well with a small bias but having a larger root-mean-square (RMS) difference (1.7m/s). These differences are acceptable for operational purposes. In a second study upper-air soundings were made at Port Hardy and an intercomparison of wind, temperature and humidity measurements was carried out. The temperature measurements agreed, on average, to within 0.3°C with an RMS of about 1°C. There were larger and significant differences in the humidity measurements. These differences reflect the differences between two types of radiosondes. The wind differences between the Navaid system and the radio theodolite tracking were, in the mean, about the same as the radar-Navaid differences, but the RMSs were about twice as large. (*Contact: G.A. McBean.*)

Canadian Wildlife Service



During the year, three studies of water birds were completed by CWS. One compared the selection of habitat by nesting Mew Gulls of Vancouver Island lakes to that of the Glaucous-winged gulls nesting in the Gulf Islands. Another compared the nesting biology of Mew Gulls on Vancouver Island with that of the species in Scandinavia and the U.S.S.R. The third examined the nesting habits and habitat of Ancient Murrelets and Cassin's Auklets in the Queen Charlotte Islands.

The purpose of the Mew Gull studies was to determine nesting populations and the types of lakes and islands on Vancouver Island selected for nesting purposes. The intent of the Ancient Murrelet and Cassin's Auklet study was to determine why the Queen Charlotte Islands has the largest nesting population of Ancient Murrelets and the second largest of Cassin's Auklets in the world. (*Contact: Kees Vermeer.*)

A major project (started in 1985) by the Canadian Wildlife Service (CWS) at the Institute of Ocean Sciences was a study of the population dynamics of the Glaucous-winged Gull in the Strait of Georgia. This is the only gull species that nests in the marine habitat of British Columbia. Although it is numerous, and rapidly expanding, it nevertheless makes up only two percent of the nesting seabird population in British Columbia. More numerous are the several species of alcids, such as the Ancient Murrelets, Cassin's Auklets, Rhinoceros Auklets, and Fork-tailed and Leach's Storm-Petrels. These birds are less frequently seen by public than are gulls because they chiefly breed on the outer west coast; they are nocturnal, visit colonies at night, and nest in burrows dug into the soil.

The Glaucous-winged Gull has increased steadily since the 1920s. Before then it was not very numerous on our coast; however, urbanization in southern British Columbia has led to an increase in human refuse upon which the gulls feed, particularly during the winter season. The prevailing theory is that the gull population before the 1920s was limited because of heavy winter mortality. In the winter, the gulls' access to intertidal foods is limited since low tides occur at night and they are not nocturnal foragers. The increase of human refuse in garbage dumps and offal from fishing activities may have reduced the gulls' winter mortality over the past several decades. Another reason for the increase in gull numbers in recent years may be that "egging" of nesting colonies has gone out of fashion. In contrast, at the beginning of this century egging

was carried out at such an alarming rate that guards were posted at some nesting islands to protect the colonies from this activity.

The first major survey of the Glaucous-winged Gull nesting population in the Strait of Georgia was conducted in 1959-1960; a second one took place in 1974-1975. It was found that the gull population had increased greatly between 1960 and 1975. A third survey of the nesting population is planned in 1986 to determine if this increase is continuing. Results of a preliminary survey of colonies in the Gulf Islands in 1985 indicated that such may actually be the case, as increases in gull numbers, as well as in nesting colonies, are found to have occurred. During the last few decades Glaucous-winged Gulls have also invaded the cities and are now nesting in the hundreds on the roofs of buildings along Burrard Inlet and False Creek in Vancouver. An over-abundance of these gulls could result in human health hazards, safety hazards near airports, and displacement of other bird species. It is for these reasons that the present population growth curve will be examined. If the gull population continues to grow, measures may have to be taken to control the nesting population.

(Contact: Kees Vermeer.)

DEPARTMENT OF ENERGY, MINES AND RESOURCES

Pacific Geoscience Centre

Earth Physics Branch and Geological Survey of Canada

Director's Foreword



The Pacific Geoscience Centre (PGC) had a very productive year in 1985. A number of important short term national and western Canadian geoscience needs were met and there have been many exciting new achievements in fundamental geoscience. Some of the highlights:

The Offshore Boundaries Program that is to end in March 1986 provided funds for extensive studies on the Juan de Fuca Ridge as well as along the continental margin. It permitted compilation of a comprehensive geoscience data base for the west coast and Beaufort Sea offshore that is not only essential for boundary negotiations but that will be very valuable for many other uses. Along with the Frontier Geoscience Program it also provided funds for several contracted multichannel seismic lines across the Vancouver Island continental margin and a contracted extensive SeaMARC II acoustic imaging survey both on the Juan de Fuca Ridge system and along the edge of the continental shelf. The offshore seismic lines provided an extension of last year's Lithoprobe Vancouver Island lines.

A highlight of the Juan de Fuca Ridge work was the discovery and sampling of a "sediment-hosted" sulphide mineral deposit in a sediment pond near the north end of the Juan de Fuca Ridge proper. This type of deposit is potentially very large. On land such deposits are among the largest found and are of particular economic importance.

The Frontier Geoscience Program continued at a higher level its studies directed toward the petroleum potential along the western margin of Canada and in the northern Yukon-Beaufort Sea region. In addition to the seismic and acoustic imaging surveys, the Program allowed for a wide range of geoscience studies including an aeromagnetic survey of the Queen Charlotte area. Interest in petroleum exploration in the area has increased. A Panel responsible for recommending on what conditions exploration can continue has held public hearings and will report in the near future.

Increasing effort is being directed toward the International Ocean Drilling

Project (ODP) by PGC scientists. Participation onboard the ship *JOIDES Resolution* is planned for 1986-7, and surveys have commenced for holes to be drilled off the Canadian west coast in 1989-1990.

Two significant earthquakes of magnitudes near 7 occurred in the Nahanni area of southwestern Northwest Territories in October and December, the largest events in Canada for 15 years. The region has had relatively low previously recorded seismicity and these events may have an important impact on earthquake risk estimates for the region. Field parties from PGC did aftershock and other studies in the area following both events in spite of the remote location and the severe difficulties of working in the northern winter.

Important for the future of the Pacific Geoscience Centre was the announcement that as of April 1, 1986 the Earth Physics Branch is to be merged with the Geological Survey, and that PGC is to be merged into one division with the Cordilleran Geology Division of Vancouver. Although coupled with difficult but hopefully small reductions in resources, the reorganization will permit PGC to operate as one unified group. A time of change is always a time of uncertainty and concern, but I am confident that the future is bright.

The staff of the Pacific Geoscience Centre working together have created a geoscientific research establishment that is second to none, and of which we can all be extremely proud.



Marine Sedimentology

Estuarine and Marine Delta Sedimentation

As in previous years demand remained high for geological data from the Fraser River delta which can help formulate environmental/engineering guidelines. During 1985 results of geological research have been applied to a wide range of projects sponsored by other agencies including assessments of the physical/biological impact of the expansion of the Roberts Bank Coal Port, the design of an appropriate dyke for the Tsawwassen Indian Reserve marsh on Roberts Bank and creation of intertidal dredge spoil islands on which marsh habitats can be established.

Highlights of the summer's field activities include a trial survey of the

structure and lithology of the Fraser delta employing high resolution seismic reflection profiling, electrical resistivity surveying and coring. This program likely will be expanded into a major multidisciplinary research effort involving government, university and private sector personnel. The acquired geological data should enhance assessments of seismic risk for the area. Major milestones have been achieved in two delta-related theses studies supported by the Geological Survey of Canada at the Geography Department of Simon Fraser University. The results of one study provide, for the first time, direct evidence of a "proto-delta" below the surface of the eastern part of the present delta. The second study has identified the advantages of airborne multispectral mapping techniques over satellite systems for mapping local coastal environments. Field work performed jointly with the Department of Geography at the University of British Columbia in the outer reach of the main channel of the Fraser River established that suspended load increases with increasing river discharge and decreasing tidal elevation and that most sediment is transported in suspension rather than as bedload. The results of this study will be applied to assessments of the stability and sediment budget of the delta front. (*Contact: J.L. Luternauer, now at Geological Survey of Canada, Vancouver.*)

Fiord Studies

Studies of underwater slope failures in British Columbia fiords are continuing in a number of areas. Following the catastrophic draining of an ice-dammed lake in 1984, South Bentinck Arm was surveyed using side scan sonar and seismic reflection to determine if any offshore failures occurred as a result of the rapid delivery of large quantities of sediment to the delta. Broad channels with large scale bedforms and incipient slope failures were found to be common on the lower parts of the delta and may be related to the flood.

Studies of long-distance sand transport through channels in Bute Inlet, in cooperation with Louisiana State University, continued with the installation of three moorings, consisting of tilt sensors, current meters and water bottles. Bottom-mounted acoustic transponders were installed in order to detect seabed movement during the one-year deployment period.

Debris torrents in creeks along the eastern shore of Howe Sound have resulted in considerable property damage and loss of life. To assist in planning protective structures in this area, the nearshore zone was surveyed using echosounding and side scan sonar. (*Contact: B. Bornhold.*)

Continental Shelf Studies

Research continued on the character and genesis of submarine slope failures, coarse gravel beds, active sand wave fields and shallow subbottom gas accumulations in Queen Charlotte Sound. All of these factors are important for hydrocarbon exploration and development in this area of the continental shelf. The project has established that few if any major slope failures have occurred during the last 10,000 years. As part of this project the remanent magnetization is being measured on samples taken from radiocarbon dated sediment cores collected in Queen Charlotte Sound. This information should allow sedimentation rates to be established and the correlation of geological units and geological events in different areas of the sound. (*Contact: J.L. Luternauer, now at Geological Survey of Canada, Vancouver.*)

Mapping of the surficial geology and morphology continued off northwestern Graham Island including a contract survey. The survey, in water depths from 5 to 70m, involved precision echosounding, side scan sonar mapping and grab sampling. As with the area off central northern Graham Island completed in 1984, three 1:25,000 maps of bathymetry, morphology and sediment type have been produced. (*Contact: B. Bornhold.*)

Juan de Fuca Ridge Sediment Studies

A one-month cruise was carried out to Middle Valley on the northern Juan de Fuca Ridge that included an investigation of the nature of sedimentation in an area of very high heat flow. Forty-two sediment cores were collected, many of which revealed evidence of hydrothermal input. One core obtained from an apparently hydrothermal mound structure consisted of over 2m of massive iron and zinc sulphides. Zinc values ranged from 2.7 to 4.6%. Other cores contained anomalous manganese and barium rich layers, pebble-size calcium carbonate nodules, and layers of coarse-grained, crystalline material, probably barite. (*Contact: B. Bornhold, E. Davis.*)

Yellow River Delta, People's Republic of China

An international team from Canada, the United States and China carried out a reconnaissance study of sedimentation on the offshore areas of the present Yellow River (Huanghe) delta and adjacent Bohai Sea. The work involved multi-frequency echosounding, sub-bottom profiling, side scan

sonar traverses, coring, deployment and recovery of current meters and suspended matter sampling. Studies in the summer of 1986 will attempt to document the processes related to the dense turbid underflow during the main flood of the river. (*Contact: B. Bornhold.*)

Sedimentology Laboratory

The sedimentology laboratory provided technical and analytical support for the following projects: estuarine and deltaic sedimentation, continental shelf sedimentation, fiord studies, continental shelf mapping, Juan de Fuca Ridge studies, and mud underflow dynamics. Samples from 80 cores, 625 grabs and two dredges were received from twelve field expeditions. Sixty cores were opened, lithologically described and subsampled; 625 grainsize analyses were completed; 270 subsamples were analysed for CaCO_3 ; 125 subsamples were prepared for micro faunal analyses; 15 shell samples were prepared and sent off for C^{14} dating; 200 subsamples were prepared for paleomagnetic measurement. All of the samples and subsamples were archived.

The sediment lab operation was improved with the settling tube and sedigraph data being directly logged by a microcomputer and the data then being merged with gravel weights and field information. Data storage and retrieval, plus subsequent analysis and generation of statistics is greatly facilitated.

The data base for field information now totals 9500 samples from the west coast of Canada and the northern Pacific. This data base has been transferred to a microcomputer. Samples can be referenced by sample type, sample number, location, depth, analysis etc. and printouts of the field data and sample locations can be generated. In the next year the data base will be expanded to include the analytical data, and the plotting capability will be increased.

Eight groups external to the Pacific Geoscience Centre, six associated through joint projects, contributed samples in the past year. There were 21 requests for data and/or samples. (*Contact: T. Forbes.*)



Marine Geology— Bedrock Geological Studies

Lithoprobe Geological Studies

As part of the ongoing Vancouver Island Lithoprobe experiment, geological mapping at a scale of 1:50,000 was completed across central Vancouver Island (*A. Sutherland Brown*). Stratigraphic and structural relationships within the Paleozoic Sicker Group reveal long-lived caldera complexes and island arc volcanism associated with sulphide mineralization. Detailed studies along the Beaufort Range identified the primary Late Cretaceous timing of the Beaufort Range—Cowichan thrust fault system. (*Contact: C. Yorath.*)

Offshore Seismic Reflection Profiling

Approximately 900 km of multichannel seismic reflection profiles were shot across the shelf off the west coast of Vancouver Island under contract, and concurrent gravity and magnetic data also were obtained. About 515 km of the seismic data have been processed. Preliminary results reveal the Juan de Fuca plate dipping easterly beneath the continental margin, showing a correlation with the plate seen on the Vancouver Island Lithoprobe profile. Beneath the continental slope, easterly dipping thrust faults dislocate the sedimentary prism above the Juan de Fuca plate. High level structure appears to show tectonic wedging and delamination similar to that known to be present beneath the foothills of western Alberta. (*Contact: C. Yorath.*)

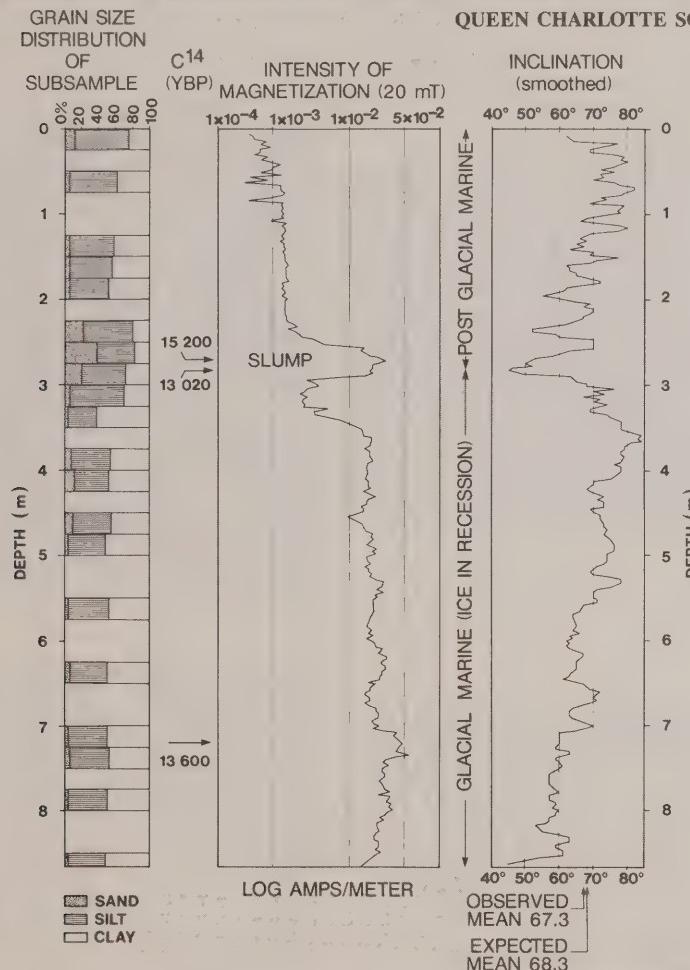
Queen Charlotte Islands

Studies of the lavas of the Tertiary Masset Formation are part of a continuing series of investigations into the volcanics of the Insular Belt and adjacent deep ocean. Efforts in 1985 focussed on detailed stratigraphic and structural studies and 1:20,000 scale geological mapping in the McKay Range of central Graham Island and in parts of the Moresby Archipelago. New findings include lateral facies changes in these 21 to 17 million year old volcanics controlled by the proximity to local eruptive centres and by the subsequent effects of Late Tertiary structures which cut the volcanic pile. These structures include both

high angle strike slip faults (oriented ENE) and easterly dipping low angle faults (thrusts) which imbricate the section. Recognition of these structures is important to mining exploration both for their potential disruptive effect on old stratabound copper mineralization and their potential localizing effect on younger hydrothermal gold mineralization.

REMNANT MAGNETIZATION OF CORE HUDSON 81 II-08

QUEEN CHARLOTTE SOUND 1981



Grain size distribution and magnetization of sediment in a core collected in a basin in southern Queen Charlotte Sound. Note distinct magnetic signature of different deposits and apparent regular secular magnetic variations in the upper, post-glacial sediments capping core. Once the chronology of these magnetic fluctuations is established, it should be possible to use paleomagnetism to correlate geologic events recognized in cores collected in different areas of the Sound. Note the excellent agreement between mean inclination and the expected axial dipole inclination indicating the absence of inclination error. (Research performed in association with PGC Paleomagnetics Laboratory.)

In addition, more than 45 bitumen occurrences and tar and gas seeps have been located. Half of these hydrocarbon shows occur in rocks of the Masset Formation and are interpreted to be "escape oil" from older Jurassic source beds (approximately 200 million years old). Understanding the distribution of these hydrocarbon shows is vital to constructing subsurface petroleum exploration models for the Queen Charlotte Islands and the adjacent offshore regions. (*Contact: T.S. Hamilton.*)

Geological Studies in the Strait of Georgia

The past year's activities in the Strait of Georgia have focussed on seismic stratigraphy and mapping of the unconsolidated Quaternary sediments which infill this marine basin. The total thickness ranges from near zero to more than 450 metres. The morphology of the underlying bedrock surface suggests a broad tectonic depression which has been incised in the Pleistocene by southeasterly flowing lobes of Cordilleran ice. The oldest Quaternary sediments (remnants of an earlier basin fill) are best preserved in sheltered interlobate areas as elongate drumlinoidal banks and ridges such as McCall and Halibut Banks. Early post-glacial sedimentation (about 10,000 B.P.) was restricted to the bathymetric depressions and was apparently derived by local reworking of older Quaternary deposits. By contrast, the more recent sedimentation is thickest off Roberts and Sturgeon Banks and clearly has the Fraser River as a sediment source. An understanding of these young sedimentary deposits is fundamental both to geotechnical assessments for submarine development and to an accurate representation of glacial and modern geological processes in the region. (*Contact: T.S. Hamilton.*)

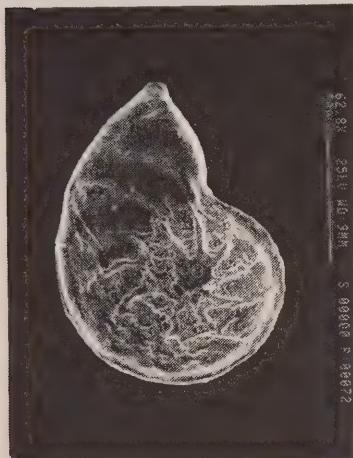
Decade of North American Geology

As a contribution to Decade of North American Geology, a multi-volume series on the geology of North America, the volume on the Canadian Cordillera is nearing first draft completion. Twenty six chapters describe the geological architecture, tectonic history and resources potential of the Cordillera including the continental margin. Contributions from the Pacific Geoscience Centre include chapters and sections on Upper Jurassic to Paleogene stratigraphic assemblages, Neogene assemblages, structural style and resources potential of the Insular Belt, modern plate tectonic regime, Cordilleran geophysics and paleomagnetism. (*Contact: C. Yorath.*)

Palaeontology



Activities in palaeontology and biostratigraphy in 1985 centered on the Jurassic and Cretaceous foraminifers and the stratigraphy of the Queen Charlotte Islands. Several new stratigraphic units have been recognized, some of which have significance as primary hydrocarbon source beds, others may prove to be good stratigraphic hydrocarbon traps in subsurface.



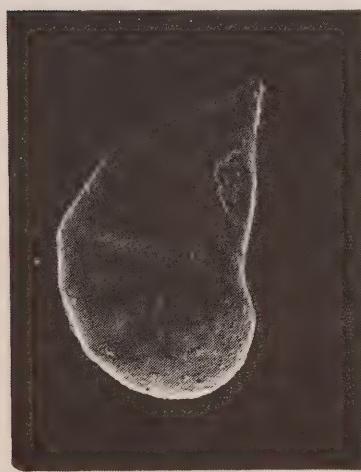
Lenticulina d'orbignyi (Roemer)



Lenticulina gottingensis (Bornemann)



Lenticulina prima (d'Orbigny)



Lenticulina sp. T1



Kinkelinella sp.



Citharina sagittiformis (Terquem)



Falsopalmula varians
(Bornemann)



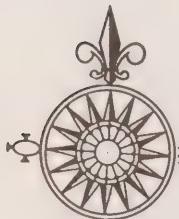
Vaginulina listi (Bornemann)



Reinholdella cf. macfadyeni
(Ten Dam)

Scanning electron microscope micrographs of Jurassic foraminifers of the Queen Charlotte Islands.

The Jurassic and Cretaceous of the Queen Charlotte Islands spans approximately 120 million years between 200 to 87 million years ago. The rocks are composed of a complex sequence of mixed volcanic and sedimentary rocks which carry rich faunas of both macro and microfossils. There are an estimated 700 species of foraminifers throughout this section which provide an excellent means of dating the rocks, and indicate the environments in which the rocks were deposited. (Contact: B.E.B. Cameron and M. Johns.)



Multiparameter—Geophysical Surveys

Systematic magnetic, gravity and bathymetric surveys have been conducted over the Canadian Exclusive Economic Zone to help assess the economic potential of the region and its tectonic framework.

During this year's marine program 9000 kilometres of geophysical data were collected on a 4 week cruise aboard CSS *Parizeau*. The region surveyed was between 46° and 51°N and from 100 to 200 nautical miles offshore. The 1985 cruise marked the culmination of a multiyear program which started in 1973. Approximately 93,000 kilometres of data have been obtained in an area from the Strait of Juan de Fuca to Dixon Entrance

out to 200 n.m. offshore. The line spacing has typically been 5 km at the inshore continental shelf ends of the lines, to 10 km at the 200 n.m. limit.

The gravity data set of some 47,000 survey points has recently undergone a network adjustment in the Ottawa gravity laboratory involving approximately 2400 crossovers yielding a standard deviation of 1.05 mGals (1 part in 1,000,000 of the earth's gravity). Similar processing is underway for the magnetic data which will be released in 1986.

In addition to the major offshore survey, 750 kilometres of gravity and bathymetric data were collected in Georgia Strait in 1985.

(Contact: R.G. Currie and D.A. Seemann.)

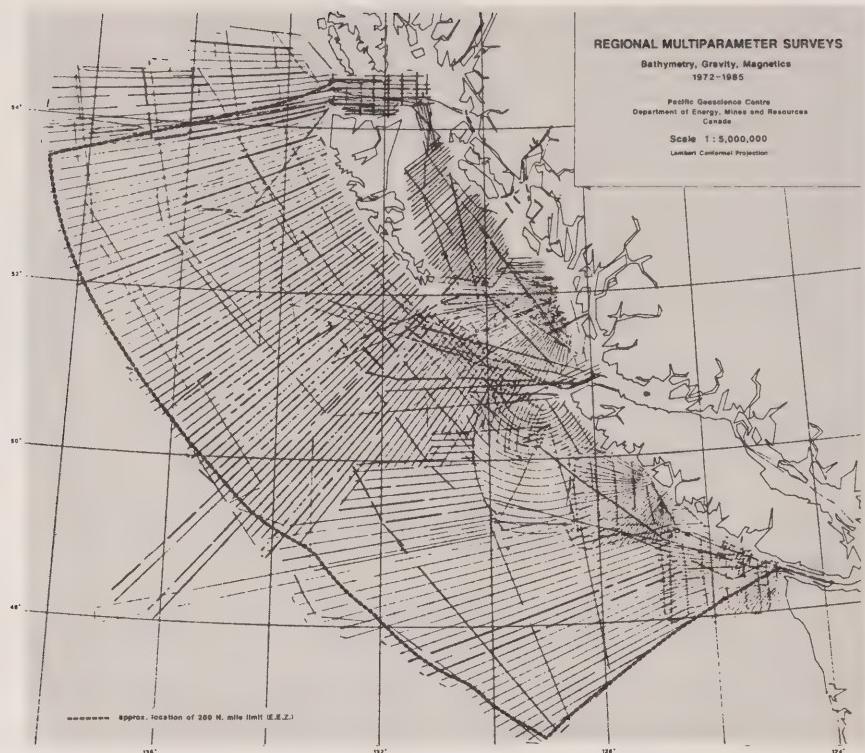
Juan De Fuca Ridge and Offshore Mapping



Detailed SEABEAM high resolution swath bathymetry mapping efforts are continuing in a cooperative effort with S. Hammond of the National Oceanographic and Atmospheric Administration (NOAA), with the production of several new 1:50,000 ten m contour map sheets and 1:250,000 regional compilations over the northern Juan de Fuca Ridge system. The maps continue to be put to extensive use both for direct tectonic interpretation and as base maps for geophysical and geological studies using deep-towed and bottom-deployed instruments, cameras and sampling, and using the research submersibles *Alvin* and *Pisces*.

(Contact: E. Davis, R.G. Currie and B. Sawyer.)

Mapping of the seafloor off western Canada is also continuing, in cooperation with the Hawaii Institute of Geophysics, with the SeaMARC II acoustic imaging system. Extensive surveys were completed this year over the central Juan de Fuca and northern Explorer Ridges, and the Vancouver and Queen Charlotte Islands continental margins. Features of particular interest included the highly asymmetric distribution of off-axis volcanism near the Explorer and Juan de Fuca Ridge crests and the frequent occurrence of massive slope failures along the first compressional fold of the underthrusting zone at the base of the Vancouver Island continental slope. (Contact: E. Davis, R.G. Currie and B. Sawyer.)



Composite ship's track showing coverage obtained from 1972 to 1985 inclusive.



International Ocean Drilling Project

In 1984 Canada became a member of the International Ocean Drilling Project (ODP). This project will lead both to deep sea boreholes adjacent to Canada that will make critical contributions to our understanding of the Canadian offshore and to the involvement of Canadian scientists in the forefront of marine geoscience research around the world. The involvement of PGC scientists in specific cruises of the drilling ship *JOIDES Resolution* is planned starting in 1986. At present PGC has extensive involvement through membership on the Canadian National Committee for ODP, and on the advisory panels: Central and Eastern Pacific Regional Panel (CEPAC), Western Pacific Panel (WPP) and Southern

Oceans Panel (SOP). Several papers on the crustal structure, physical properties and hydrothermal circulation regime of a region of the Mid-Atlantic Ridge from a previous drilling leg were published this year.
(Contact: R.D. Hyndman, B.D. Bornhold, C.J. Yorath and E.E. Davis.)

Seismological Service



The Seismological Service provides earth scientists, civil engineers, resource development industries and the public with basic earthquake data and with research information concerning natural and induced earthquakes, ground motion, seismic risk, earth structure, and nuclear explosions. This is accomplished through a network of seismological stations, including standard and regional stations, two telemetered arrays, strong motion accelerographs and special installations. A total of some 50 seismograph stations are now operating in western Canada.

Special Seismic Networks

The Western Canada Telemetered Network (WCTN) provides centralized, on-line monitoring of seismicity in southwestern British Columbia. Eighteen stations are recorded at the Pacific Geoscience Centre (PGC), including 3 stations of the University of B.C. network.

The regional network in the Queen Charlotte area has been strengthened this year by the addition of three stations on Moresby Island and one station in Prince Rupert. The Beaufort-McKenzie regional network, formerly operated in cooperation with Dome Petroleum Ltd., has been restructured and is now operated by PGC. Data from the coastal stations at Komakuk Beach and Single Point are now sent on telephone lines to Inuvik where they are recorded on paper. The network is completed by regional stations at Sachs Harbour and Dawson.

The strong motion seismograph network in western Canada consists of instruments designed to operate and record ground acceleration only when very strong ($\frac{1}{2}\%$ of normal gravity or larger) earth motion occurs. During 1984, one new instrument was added in the Queen Charlotte area for a western Canada total of 36 accelerographs. A review of the growth and current status of the Canadian strong motion program was prepared for the International Association of Seismology and Physics of the Earth's Interior. The Miramichi, New Brunswick earthquake series of 1982 has

given a significant impetus to the development of the Canadian strong motion instrumentation program. The accelerograph network of the National Research Council is now under the direction of Earth Physics Branch and extra funding has been made available for upgrading the western network. Three strong motion instruments were installed in the Nahanni area of S.W. Northwest Territories following an October event. Unique strong motion records were obtained by the instruments from a subsequent $M = 6.9$ event in December in the same area. Two of the instruments were very close to the hypocentre and recorded maximum horizontal acceleration of some 1.25 g and vertical acceleration of over 2 g . (Contact: D.H. Weichert.)



One kilometre-wide landslide triggered by October 5, 1985 Nahanni earthquake.

Seismic Risk

PGC continues to supply site specific seismic risk calculations. Use of the extreme value method of Gumbel, as specified in past versions of the National Building Code of Canada, has been discontinued. Calculations

are now based on Cornell's method as described in the 1985 edition of the Code. (*Contact: D.H. Weichert.*)

Special Earthquake Studies

Expansion of the telemetered seismograph array in late 1984 has made it possible to study the focal depths and focal mechanisms of microearthquakes in the central region of Vancouver Island. Preliminary analysis suggests almost all earthquakes are within the subducted plate beneath Vancouver Island and none have mechanisms consistent with slippage on the subduction thrust interface between the two plates.

A comprehensive data base of earthquakes and arrival times for the region west of Vancouver Island has been compiled. (*Contact: G.C. Rogers.*)

Western Canada Seismicity

The Pacific Geoscience Centre is responsible for locating all earthquakes recorded in western Canada for inclusion in the National earthquake data file. During 1985, approximately 1,000 earthquakes were located. The two largest earthquakes, magnitude 6.6 on October 5 and magnitude 6.9 on December 23, occurred in the Nahanni area of the Mackenzie Mountains about 160 km west of Fort Simpson, N.W.T. These were the two largest earthquakes on land in Canada in about the last 40 years. Both were very widely felt over most of western Canada. No serious damage was reported, mainly due to the low population density in the epicentral region. Field surveys were conducted after each event to determine the nature and extent of the aftershock sequences and to examine macroseismic effects such as landslides. Aftershock activity is continuing with events as large as magnitude 5. (*Contact: R.B. Horner.*)

Elsewhere in western Canada, 14 other earthquakes were reported felt. These included four near southern Vancouver Island, one in southern mainland B.C., two on the Queen Charlotte Islands, three in southwestern Alberta, one in Saskatchewan and three in the southwest Yukon Territory. (*Contact: R.B. Horner, G.C. Rogers and D.H. Weichert.*)



Gravity

The principal mandate of the Gravity Service is to establish the shape of the geoid in Canada to the highest standards and to determine the value of gravity on a regional basis over the Canadian landmass and offshore areas. The regional gravity data are used in both the determination of crustal structure and the evaluation of resources and are critical to the operation of inertial navigation systems used by defence and other agencies.



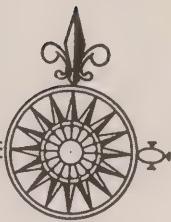
Measuring gravity at a surveyor's cairn in the Ogilvie Mountains, Yukon.

In conjunction with the Lithoprobe program, a detailed gravity study was conducted this summer in the area of the proposed transect in the Mackenzie Basin between Inuvik and the Beaufort Sea. Gravity measurements collected from over 200 stations will provide valuable information on crustal thicknesses and aid in the interpretation of seismic reflection data to be collected along the transect early in 1986.

The digitizing of one kilometre elevation/depth information used in the computation of terrain corrections was continued under contract. Most of British Columbia (including a large portion of the offshore area) and the Yukon Territory have now been covered as well as adjoining areas in Alberta, Northwest Territories, Alaska and Washington. The Digital Terrain File which resides in a System 2000 data base maintained by the Gravity Data Centre, Ottawa now contains approximately 2.3 million spot elevations and water depths.

The marine component of the gravity program was active this year and is discussed in the "Multiparameter-Geophysical Surveys" section. A

contract for an extensive underwater gravity survey off the Canadian east coast was also managed on behalf of the Department of National Defence.
(Contact: J.F. Sweeney, D.A. Seemann and J.B. Boyd.)



Geothermal Studies

In 1985 the geothermal program continued its studies related to understanding the western Canada and offshore thermal regime, including its relation to tectonic processes and to geothermal energy potential. The measured thermal parameters include field measurement of surface heat flux (the product of vertical temperature gradient multiplied by the thermal conductivity of the rocks) from boreholes and from seafloor probes and of the heat generation from naturally occurring isotopes of uranium, thorium and potassium. Studies covered a wide range of geological and geophysical interests, including the processes involved at the Juan de Fuca Ridge, the aging and cooling of the plates, the subduction along the west coast margin, tectonic and volcanic processes in the Cordillera and the potential for geothermal energy.



Variation in heat flux as a consequence of the subducting oceanic plate.

Continental Geothermal Studies

The analysis of heat flux data along the Vancouver Island Lithoprobe Profile showed that the main, deep seismic reflectors are nearly isothermal, and the deepest is approximately 450°C. Thermal modelling of the subducting plate indicates that it must be kept cool in order to have the brittleness to sustain earthquakes. Consequently, fluid flow and/or endothermic metamorphic reactions must be occurring along the horizons defined by the dipping, isothermal seismic reflectors.

An 11m telemetry heat flow probe was built, tested and used in the northern B.C. fiords. This probe allows a greater depth of penetration into the soft bottom sediments, helping to overcome transient problems caused by changes in bottom water temperatures of the fiords.

Two boreholes were drilled in the Fraser Valley to help define the heat flux distribution along an east-west profile. The object was to look for the large heat flux transition which occurs to the north along Jervis Inlet, 30 km seaward of the Garibaldi Volcanic Belt and for possible low grade geothermal energy potential in the upper Fraser Valley. Geothermal data were also obtained from boreholes drilled for mineral exploration near Duncan, Rossland, Adams Lake and Harrison Lake, B.C., as well as in southern areas of the Yukon. (*Contact: T. Lewis and W. Bentkowski.*)

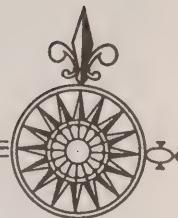
Oceanic Geothermal Studies

One exemplary study was completed over the northern Juan de Fuca Ridge at a location where the rift axis is completely buried by turbidite sediments from the nearby continental margin. A number of unusual mounds observed in the new SEABEAM bathymetry and previously published SeaMARC II acoustic image data along the eastern side of the sediment-filled rift valley were suspected to be of hydrothermal origin. A detailed study of these features was completed using piston coring, bottom photography, heat flow, and high and medium frequency seismic reflection profiling. The presence of very large heat flow anomalies in the vicinity of the mounds and the recovery of hydrothermal sulphide sediments from one of the mounds verified their hydrothermal origin. The mounds appear to be present-day analogues to many massive sulphide ore deposits found now on land. (*Contact: E. Davis and B. Bornhold.*)

The analysis of high-accuracy heat flow measurements from several Jurassic basins of the western Pacific was completed, and the data verify

that the heat flow in these basins is too high to be explained by any simple cooling history. A major lithospheric reheating event since the time of seafloor creation is implied. (*Contact: E. Davis.*)

Geomagnetism



The Geomagnetism Group has programs in observatory monitoring of changes in the geomagnetic field, in the use of rapid variations to determine earth structure and properties and paleomagnetism.

The Geomagnetic Field

To be utilized for navigation, the magnetic field and its gradual change with time must be determined as a function of latitude and longitude. In addition, changes must be monitored to correct for transients in magnetic survey data and for a variety of other purposes. As part of the Canadian Geomagnetic Network of 13 primary observatories, PGC operates the Victoria Geomagnetic Observatory on property at the Dominion Astrophysical Observatory. (*Contact: L. Law and D. Auld.*)

Geomagnetic Variations

Temporal variations in the earth's magnetic field provide an electromagnetic source with which to probe the earth's electrical conductivity structure using a technique called magnetotellurics. Electrical conductivity is an important parameter in understanding the active tectonic regions on the west coast. Deep zones of high conductivity, related to high temperatures and partial melting, determine the maximum thickness of the cold lithosphere riding over the asthenosphere. Conductive zones at shallow depths occur in regions with geothermal resource potential.

An international electromagnetic induction experiment to investigate the structure of the Juan de Fuca Plate was carried out during 1985. This project, called EMSLAB (ElectroMagnetic Sounding of the Lithosphere—Asthenosphere and Beyond), included the largest array of land and seafloor magnetometers ever deployed. The array spanned from the ridge, where new material forms, across the Cascadia Basin to the coastal region where the Juan de Fuca Plate sinks deep below North America,



Recovery of ocean bottom instrument used in a EMSLAB project.

and to the other side of the Cascade Volcanoes, produced by the remelting of the plate. The data are currently being analysed. The results will yield an image of an oceanic plate from birth to death.

Results from controlled-source electrical soundings and heat flow measurements obtained near the Juan de Fuca Ridge in 1984 show that this combined analysis greatly constrains most of the physical properties of the sediments.

A two-dimensional electrical conductivity model has been constructed to simulate the subduction of the Juan de Fuca Plate beneath Vancouver Island, Strait of Georgia and coast ranges of British Columbia. The model results are in excellent agreement with the magnetotelluric responses that were obtained on Vancouver Island along the Lithoprobe transect in 1984. A good conductor was located dipping beneath western Vancouver Island which was coincident with the strongest seismic reflector and taken to be associated with the top of the downgoing Juan de Fuca Plate. The conductivity of this region suggests that the materials are porous (between 1% - 4%) and saturated with saline fluids.

The monitoring of changes in apparent resistivity, related to the increase in tectonic strain in central Vancouver Island, continued at two sites.

Following results from a site located on a fault zone in Japan that showed a marked decrease in electrical potential preceding a magnitude 4.9 earthquake, site testing was completed for a third station directly on the Beaufort Range fault. This fault is thought to be the locus of the major 1946 earthquake.

A preliminary map was compiled in digital format showing the major terrane boundaries for the Juan de Fuca map area. An overlay of the terrane map allows correlations to be made with other compilations of geophysical data in the Juan de Fuca map series, namely magnetic anomalies, seismicity, heat flux, and gravity anomalies. (*Contact: L. Law, J. DeLaurier, D. Auld and D. Nobes.*)

Paleomagnetism

Paleomagnetic work at PGC is concerned primarily with the tectonics of the Cordillera and the western Arctic, and with magnetostratigraphic studies. During the last decade, geological and geophysical studies have shown that the Cordillera comprises a number of distinct crustal blocks. Paleomagnetic work has shown that these blocks have been transported from the south by distances of over 1000 km. This discovery that the western Cordillera is a collage of accreted crustal fragments has led to a profound revision of ideas about the origin of this and other mountain belts.

Three major programs are underway. The objective of the first is to collect a suite of rocks along a traverse across the Cordillera from Vancouver Island to the Rockies in order to determine the relative latitudes of the various crustal elements at different geological instants in time. The Middle Cretaceous (100 Ma) traverse is now well in hand, and traverses for the Late Triassic—Early Jurassic (200 Ma) and the Early Tertiary (Eocene) are in process of development. The second program calls for sampling from the northern rim of the Sverdrup Basin in Ellesmere Island. The third program is concerned with the study of secular variation of the geomagnetic field recorded in recent sediments, in fiords and on the continental shelf of British Columbia.

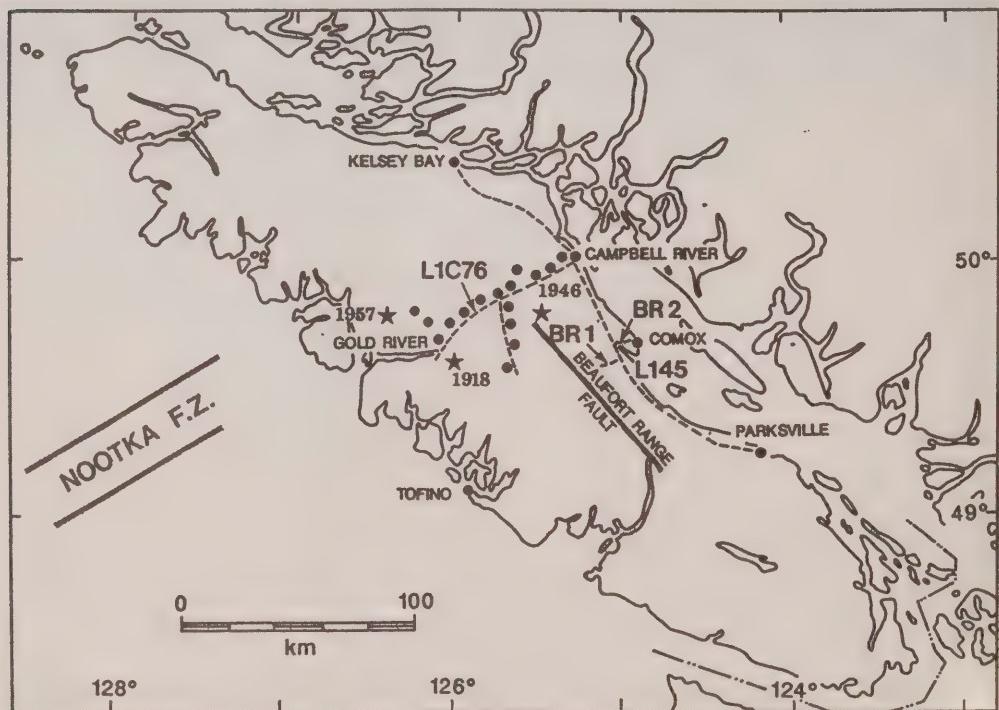
The main collections made in 1985 were in collaboration with Queens and Carleton Universities. We have also made considerable progress in compiling a Canadian catalogue of paleomagnetic results, and have completed a review of all paleomagnetic work in the Cordillera, in which

we have attempted to relate the motions of various terranes to the motions of the oceanic plates to the west. (Contact: E. Irving and P.J. Wynne.)



Geodynamics

The current focus of geodynamic studies on the west coast of Canada is contemporary crustal deformation effects at the active plate margin. The scientific objectives include gaining a better understanding of current plate interactions in the Juan de Fuca subduction zone, and relating contemporary secular deformation processes to current seismicity and potential major future earthquakes.



Location of the geodetic surveys carried out on central Vancouver Island for the purpose of measuring deformation. Dots represent precise gravity station and the fine dashed lines (L1, L2, L3) show lines of repeated levelling. Stars annotated with a date mark the epicentres of the three large (M greater than 6) earthquakes which occurred this century.

Three geodetic measurement techniques are being applied in the area of central Vancouver Island to monitor on-going crustal deformation: repeated precise gravity, vertical control (levelling), and horizontal control (trilateration, triangulation) surveys.

Precise gravity surveys which monitor a combination of relative changes in elevation and crustal densities were initiated in 1977. A reoccupation of the network of stations established at that time was again completed by contract in August 1985. Most of the gravity changes so far observed are less than $15 \mu\text{Gal}$ and can be related to local effects, i.e. changes in water levels of the Strathcona Reservoir or changes in the local groundwater table. No significant long-term linear gravity trends have been resolved at any of the network sites.

Repeated precise elevation measurements of benchmarks along highways are used to measure regional tilting of the earth's surface. During the past year, levelling was again carried out by the Geodetic Survey of Canada between Campbell River and Gold River in order to check for continued east-west tilting suggested by a comparison of the 1976 and 1981 surveys. Unfortunately, the presence of systematic errors in the earlier surveys prevents a clear resolution of current tilt rates. However, the best estimate is that the Campbell River region is uplifting with respect to Gold River at a rate of 1 or 2 mm/a. As part of this work, a thorough investigation of the effects of systematic errors on these levelling data was carried out. It appears that the 35 mm of uplift of Campbell River with respect to Parksville determined from surveys carried out in 1977 and 1984 is real and cannot be accounted for by systematic errors. It could reflect deformation associated with a major earthquake cycle.

Trilateration measurements using laser-ranging instruments can monitor changes in distances as small as a few millimetres over tens of kilometres. A network of mountain-top stations, established in 1981 in the Gold River area, was again surveyed by the Geodetic Survey of Canada in July 1985. These newer data indicate an on-going shear strain in this region of about 0.15μ strain/a (i.e. 0.15 parts in a million) of relative shortening in a northeast direction. This direction of compression is in agreement with the direction of convergence of the Juan de Fuca Plate with the North America Plate along the margin to the west.

As part of the NASA Crustal Dynamics Project which is studying deformation on a more global scale, the second occupations of the Whitehorse and Penticton VLBI (Very Long Baseline Interferometry) sites by the NASA mobile radio antenna were completed in August 1985. The Whitehorse site serves as a reference location in the study of plate

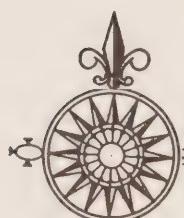
deformation in Alaska, while the Penticton site is being used in conjunction with the Yellowknife, N.W.T. and Algonquin, Ont. sites to monitor crustal deformation of the North American craton. Unfortunately, technical problems with the antenna pointing system resulted in poor quality data which prevented the calculation of any baseline distances involving these two sites for this field campaign. The project is continuing and it is hoped that the 1986 data will provide the first continental-scale strain estimates for Canada. (*Contact: H. Dragert.*)



Boundary Studies

As part of the Offshore Bilateral Boundary Geoscience Studies Program a wide range of geoscience studies were carried out along the offshore Juan de Fuca boundary. They are described in other sections. The other major Boundary Studies activity was the archiving of a bibliographic geoscience reference data base for the western Canada (Juan de Fuca, Dixon Entrance and Beaufort Sea) offshore international boundary areas. The computer data base is now largely complete. This activity, carried out in cooperation with the Atlantic Geoscience Centre, Institute of Sedimentary and Petroleum Geology, Polar Continental Shelf Project and Earth Sciences, EMR, Ottawa, through contracted and in-house studies, has assembled more than 4000 tailored bibliographic citations, 500 map/charts and a significant collection of geoscience cruise information for both the Juan de Fuca and Beaufort Sea regions.

The completion phases of this project will include optimization of retrieval software and a scientific appraisal and analyses of the data base information and marine studies mentioned elsewhere in this annual review. Presentation of these analyses will be made to the Department of External Affairs. Open File release of the assembled data files and information catalogues is proposed for late 1986. (*Contact: J.B. Boyd.*)



Technical Support

Technical Services provides electronic, mechanical and logistic support to all operating groups within PGC—both land and marine. Also, some technical support is provided to university groups and other divisions of

EMR engaged in earth sciences research. These groups include Royal Roads Military College, Simon Fraser University, the University of British Columbia and the University of Toronto, as well as Atlantic Geoscience Centre and GSC, Ottawa. The principal demand on Technical Services is the acquisition, operation and maintenance of scientific instrumentation. The year 1985 was the busiest season yet, with 19 cruises being supported.

The Sedimentology Laboratory now digitally records sediment grain size parameters as determined by x-ray sedigraph for silts and clays, and settling tube for sands. The IBM-PC based system makes data acquisition, parameter computation and data storage and retrieval much more rapid and accurate. (*Contact: T. Forbes, G. Horel and W. Hill.*)

The Paleomagnetic Laboratory ran extensive tests on a new Schonstedt Spinner Magnetometer (SSM-2) with TSD-1 furnace and an IBM-PC based controller/data logger. Also preliminary work was carried out to replace an aging LS1-II computer and Silent 700 terminal with an IBM-PC. (*Contact: E. Irving, P.J. Wynne and W. Hill.*)

An IBM-PC based data acquisition system to replace the PHAS system was successfully tested and is currently being modified in terms of both hardware and software. In its final form the system will acquire navigation information from hyperbolic LORAN C, range-range LORAN C, GPS and TRISPOUNDER; acquire additional data through 10 channels i.e. bathymetry, magnetics, gravity; pass data to an IBM-AT via a networking system for post-processing and track plotting. (*Contact: G. Horel, W. Hill and I. Frydecky.*)

A further updating of sidescan sonar capability was realized with the purchase of a 100 kHz towfish and eight channel analog recorder (4 AM and 4 FM channels). Sub-bottom profiling capabilities were enhanced with the purchase of a 3.5 kHz pinger, Teledyne 50 element-single channel streamer and two waterguns (15 cubic inch and 80 cubic inch). (*Contact: I. Frydecky, R. Macdonald and M. Bone.*)

Piston coring equipment was modified to allow instrumenting the barrels for heat flow work. A larger diameter, heavier corehead was designed to carry and protect the heat flow instrument cylinders. (*Contact: E. Davis and R. Macdonald.*)

Five PGC Ocean Bottom Magnetometers were deployed for periods of 60 to 90 days in conjunction with the EMSLAB project. One of these magnetometers remains unrecovered with dwindling hopes for retrieval.

A contract is in progress with Polar Tech Ltd. of Sidney, B.C. for

development and construction of an improved telemetering heat probe for in-situ ocean-bottom measurements of thermal gradients and conductivity. The new probe will feature solid-state data logging with interactive operator control of all control parameters.

An 11-metre long thermistor probe was fabricated and used with partial success for deep-penetration measurement of thermal gradients and conductivity in soft sediments. A second 11-metre unit has been mechanically constructed and both probes are in the process of being equipped with thermistors for use in the Queen Charlotte Sound area during 1986.

The VAX 11/750 system has been installed for the analysis of seismic data acquired by WCTN. In addition, two PDP 11/73 systems have been ordered to replace the existing PDP 11/24 and 11/40 systems for data acquisition from the 18 seismic telemetry stations of WCTN.

(Contact: M.N. Bone, A. Whitford and R. Baldwin.)

APPENDIX I

Contracts Awarded 1985

A. Department of Fisheries and Oceans

<i>Measurement of Predation Rates on Small Zooplankton by Euchaeta elongata and Euphausia pacifica</i>	
Edward Anderson Marine Sciences, Sidney, B.C.	\$ 4,392
<i>Analysis of Samples & Archiving of Data, La Perouse Monitoring Project - Zooplankton Samples</i>	
Edward Anderson Marine Sciences, Sidney, B.C.	8,021
<i>Development of Software on the IOS Image Processing System</i>	
Apocalypse Enterprises Inc., Victoria, B.C.	2,000
<i>Development of Software for the IOS Image Processing System</i>	
Apocalypse Enterprises Inc., Victoria, B.C.	29,200
<i>Develop a Ship Administration Information System Programme</i>	
Apocalypse Enterprises Inc., Victoria, B.C.	5,600
<i>Compilation of Existing Chemical Oceanographic Data Sets for the Canadian West Coast Offshore Waters, Georgia Strait, Juan de Fuca Strait, Canada Basin and Arctic Ocean</i>	
Arctic Laboratories Ltd., Sidney, B.C.	16,650
<i>Arctic Chemical Oceanographic Data Report Acquisition</i>	
Arctic Laboratories Ltd., Sidney, B.C.	10,640
<i>Compilation of Northwest Passage Zoobenthos Data</i>	
Arctic Laboratories Ltd., Sidney, B.C.	10,125
<i>Compilation of Northwest Passage Zoobenthos Data (Continued)</i>	
Arctic Laboratories Ltd., Sidney, B.C.	23,202
<i>Technical and Oceanographic Support with Gauge Mooring at Pond Inlet, N.W.T.</i>	
Arctic Research Establishment, St. Catharines, Ontario	2,500
<i>Compilation and Appraisal of Existing Physical Oceanographic Data in the Canadian Basin of the Arctic Ocean</i>	
Arctic Sciences Ltd., North Saanich, B.C.	28,083
<i>Continuation of Acoustic Measurements of Flows in Channels</i>	
Arctic Sciences Ltd., North Saanich, B.C.	\$ 39,996
<i>Development of Scintillation Radio Link and Power Transmitter System</i>	
Arctic Sciences Ltd., North Saanich, B.C.	47,860
<i>Compilation and Appraisal Report for Physical Oceanographic Data in Queen Charlotte Sound, Hecate Strait and Dixon Entrance</i>	
Arctic Sciences Ltd., North Saanich, B.C.	9,844
<i>Preparation of a Compilation and Appraisal Report for Physical Oceanographic Data</i>	
Arctic Sciences Ltd., North Saanich, B.C.	31,377
<i>Compilation of Oceanographic Data of the Nanoose Bay Underwater Test Range</i>	
Arctic Sciences Ltd., North Saanich, B.C.	39,134
<i>Upgrading Oceanographic Data Information System (ODIS)</i>	
Arctic Sciences Ltd., North Saanich, B.C.	3,500
<i>Development of a Meteorburst Drifting Buoy System, Phase I</i>	
Arctic Sciences Ltd., North Saanich, B.C.	40,000
<i>Testing of Real-time Decoding System and Design of Data Logging System</i>	
Arctic Sciences Ltd., North Saanich, B.C.	34,055
<i>Preparation of a Compilation and Appraisal Report for Physical Oceanographic Data</i>	
Arctic Sciences Ltd., North Saanich, B.C.	5,036
<i>Preparation of Report on the Nanoose Range Oceanographic Data 1967-1984</i>	
Arctic Sciences Ltd., North Saanich, B.C.	5,991
<i>Development of a Meteorburst Drifting Buoy System, Phase II</i>	
Arctic Sciences Ltd., North Saanich, B.C.	210,000
<i>Development of Specifications to Ocean Data Inventory System (ODIS)</i>	
Arctic Sciences Ltd., North Saanich, B.C.	4,995
<i>Study Ice Conditions Relevant to the Recovery of Current Meter Moorings in the Beaufort Sea</i>	
Arctic Sciences Ltd., North Saanich, B.C.	4,838

<i>Development and Theory of a Second Generation Scintillation Current Measurement System</i>		
Arctic Sciences Ltd., North Saanich, B.C.	\$ 163,087	
<i>Recovery of WOTAN Instruments from CASP Experiment</i>		
Arctic Sciences Ltd., North Saanich, B.C.	8,268	
<i>Study Effects of Increased CO₂ on Temperature and Precipitation</i>		
Atmospheric Dynamics Corp., Victoria, B.C.	10,064	
<i>Incorporation of Ice Cover in Storm Surge Model</i>		
Atmospheric Dynamics Corp., Victoria, B.C.	63,830	
<i>Incorporation of Ice Cover in Storm Surge Model (Phase II)</i>		
Atmospheric Dynamics Corp., Victoria, B.C.	66,546	
<i>Modification to Storm Surge Model</i>		
Atmospheric Dynamics Corp., Victoria, B.C.	45,975	
<i>Study of Contours of Hecate Strait 1984 in NTX Format</i>		
Barrodale Computing Services Ltd., Victoria, B.C.	3,990	
<i>Demonstration of the Hydrographic Contouring System on the VAX</i>		
Barrodale Computing Services Ltd., Victoria, B.C.	4,165	
<i>Analysis of Test and Flight Data from the FLI</i>		
G.A. Borstad Ltd., Sidney, B.C.	40,184	
<i>Collection and Analysis of Satellite and Aircraft Imagery for Studying Beaufort Sea Ice Movement</i>		
G.A. Borstad Ltd., Sidney, B.C.	30,655	
<i>Develop a Computer Sorting Algorithm for Ship-of-Opportunity Data</i>		
Broccoli Bros., Sidney, B.C.	1,214	
<i>Ship-of-Opportunity Sampling of Planktonic Ecosystem off Pacific Coast of Canada</i>		
Broccoli Bros., Sidney, B.C.	7,293	
<i>Measurement of Phyto-adaption of Marine Phytoplankton to Fluctuation of Light in Turbidostat Culture</i>		
Broccoli Bros., Sidney, B.C.	5,638	
<i>Analysis of Zooplankton Time Series Along Drifter Trajectory</i>		
Broccoli Bros., Sidney, B.C.	29,343	
<i>Field Measurement of Spatial and Temporal Variability of Photosynthetic Parameters</i>		
Broccoli Bros., Sidney, B.C.	2,008	
<i>Comparison of Syledis/GPS Positioning</i>		
Canadian Engineering Surveys Co. Ltd., Edmonton, Alberta	\$ 73,000	
<i>Provision of Navigation and Survey Positioning West of Herschel Island</i>		
Canadian Engineering Surveys Co. Ltd., Edmonton, Alberta	40,209	
<i>Multi-disciplinary Geophysical and Hydrographic Survey off the Yukon Coast</i>		
Cansite Surveys Ltd., Calgary, Alberta	65,149	
<i>Develop a Model to Predict Effects of Buried Underwater Blasting Charges on Fish Populations in Shallow Water Areas</i>		
Coastline Environmental Services Ltd., Vancouver, B.C.	103,280	
<i>Hydrographic Surveys of the Kitimat/Stewart Areas in Northern British Columbia</i>		
Coast Pilot Ltd., Sidney, B.C.	97,344	
<i>Literature Review and Preparation of a Report on the Biological and Fisheries Aspects of the Carbon Dioxide Problem</i>		
CPRO Computing Enterprises Ltd., Victoria, B.C.	7,500	
<i>Analysis of the Relationship between Sound Scattering and Temperature Microstructure and Bubble Populations</i>		
G. Crawford, Victoria, B.C.	2,560	
<i>Arctic Pack Ice Driving Forces</i>		
Croasdale & Associates, Calgary, Alberta	217,859	
<i>Compilation of Oceanographic Data of the Nanoose Bay Underwater Test Range</i>		
Dobrocky Seatech Ltd., North Saanich, B.C.	5,660	
<i>Modifications to Loran C Drifting Buoys</i>		
Dobrocky Seatech Ltd., North Saanich, B.C.	29,981	
<i>Evaluation of Metallothionein as an Environmental Indicator of the Biological Effects of Metal Levels in Natural Waters</i>		
Dobrocky Seatech Ltd., North Saanich, B.C.	236,026	
<i>Survey of Tuktoyaktuk-Driftwood</i>		
Dobrocky Seatech Ltd., North Saanich, B.C.	9,620	
<i>Drift Study to Assess Predictive Capability of a Numerical Model of the Fraser River</i>		
Dobrocky Seatech Ltd., North Saanich, B.C.	1,561	
<i>Evaluate Application of Acoustically Traced, Free Drifting "RAFOS" Floats</i>		
Dr. Dosso, University of Victoria, Victoria, B.C. ...	9,000	

<i>Historical Drill Waste Discharge</i>	<i>Analysis of Data From Prototype Sonar System</i>
ESL Environmental Sciences Ltd., Vancouver, B.C.	B. Huber, Victoria, B.C. \$ 2,400
<i>Inventory of Marine Plankton Data for Canadian Beaufort Sea</i>	<i>Preparation and Testing of Equipment for Gibraltar Strait Experiment</i>
ESL Environmental Sciences Ltd., Vancouver, B.C.	B. Huber, Victoria, B.C. 5,210
<i>Study of Variations in Somatic Characteristics of Aquatic Oligochaetes</i>	<i>Documentation and Data Analysis of Dec'84 Echometer Cruise</i>
E.V.S. Consultants, N. Vancouver, B.C.	D. Huston, Victoria, B.C. 4,000
<i>Identification and Enumeration of Marine Phytoplankton at Ocean Station P and B.C. Coastal Waters</i>	<i>Crane Dynamic Loading with Motion Compensation for At-sea Lifting Operations</i>
E.V.S. Consultants, N. Vancouver, B.C.	Hymarc Engineering Ltd., Ottawa, Ontario 91,585
<i>Identification and Enumeration of Marine Phytoplankton from British Columbia Coastal Waters</i>	<i>A Study into the Dynamics of Small Scale Variability</i>
E.V.S. Consultants, N. Vancouver, B.C.	Interact R & D Corporation, Victoria, B.C. 45,412
<i>Benthic Studies in Hecate Strait</i>	<i>Evaluation of a Statistical Theory of Tracer Transports</i>
E.V.S. Consultants, N. Vancouver, B.C.	Interact R & D Corporation, Victoria, B.C. 7,902
<i>Study of the Commercial Potential of the Galatheid Crab Munida quadrispina in B.C. Crustacean Fishery</i>	<i>Development of Data Display Programmes</i>
Galatea Research, Brentwood Bay, B.C.	Interact R & D Corporation, Victoria, B.C. 6,030
<i>Sorting of Benthic Samples in Formalin</i>	<i>Evaluation of Hydrographic Launch Dynamics Data</i>
M. Galbraith, Victoria, B.C.	Interact R & D Corporation, Victoria, B.C. 7,503
<i>Modifications to Tidal Model to Convert to a Tsunami Model</i>	<i>Development of the Oceanographic Data Inventory System-Programme Updating and Adaption to Digital Equipment</i>
G. Gatien, Sidney, B.C.	Interact R & D Corporation, Victoria, B.C. 29,989
<i>Support Services to Carry Out Multi-Laboratory Performance Checks</i>	<i>Software Changes to ISAH</i>
D. Goode, Victoria, B.C.	Interact R & D Corporation, Victoria B.C. 11,625
<i>Collection and Compilation of Oceanographic Data in the Campbell River and Fraser River Estuaries</i>	<i>Implementation of the 32 Bit Kernel, Utilities and Data Acquisition on the HAL Computer</i>
A. Hartley, Vancouver, B.C.	Interact R & D Corporation, Victoria, B.C. 1,114
<i>Continued Collection and Compilation of Oceanographic Data at Campbell River</i>	<i>Collection and Analysis of Samples from Moored and Free Drifting Sediment Traps</i>
A. Hartley, Vancouver, B.C.	ISK Environmental Research, Saanichton, B.C. ... 21,473
<i>Modifications to Shallow Water Modelling Package Developed at IOS</i>	<i>Collection, Analysis and Storage Tests of Samples and Free-Drifting Sediment Traps</i>
K. Holtham, North Saanich, B.C.	ISK Environmental Research, Saanichton, B.C. ... 24,571
<i>Preparation and Production of the Beaufort Sea Overview Report Entitled "Marine Fishes, Invertebrates and Marine Plants: The Search for Oil"</i>	<i>Preparation of a Report on Sequential and Simple Sediment Traps</i>
Hoot Productions Ltd., Victoria, B.C.	ISK Environmental Research, Saanichton, B.C. ... 988
<i>Development of an Undersea Acoustic Technique to Determine Rainfall</i>	<i>Development of an Undersea Acoustic Technique to Determine Rainfall</i>
	Jasco Research Ltd., North Saanich, B.C. 8,900
<i>Study of the Effect of Current Speed on Freezing and Melting Sea Ice</i>	<i>Study of the Effect of Current Speed on Freezing and Melting Sea Ice</i>
	D. Knigge-Seiberg, Victoria, B.C. 21,000

<i>Development of an Underwater Acoustic Imager</i>	
Knudsen Engineering Ltd., Stittsville, Ontario	\$ 238,181
<i>Chemistry Literature Review on Carbon Dioxide Project</i>	
V. Kumar, Victoria, B.C.	3,000
<i>Improvements to the Thacker Method for Tidal Models</i>	
Dr. Loomis, University of Hawaii	1,500
<i>Develop Techniques for Measuring Rainfall at Sea</i>	
Jeffrey A. Nystuen, Patricia Bay, B.C.	47,834
<i>Develop and Test an Ambient Noise Sensor for Wind Speed Measurements</i>	
Metocean Data Systems Ltd., Dartmouth, N.S.	109,753
<i>Hydro-thermal Plume Modelling Study</i>	
J.H. Middleton, Saanichton, B.C.	6,000
<i>Continuation of Technical Improvements and Evaluation of FLI</i>	
Moniteq Ltd., Concord, Ontario	33,728
<i>Continuation of Technical Improvements and Evaluation of FLI</i>	
Moniteq Ltd., Concord, Ontario	35,207
<i>Develop Electronic Imaging Techniques Using FLI for Bathymetry and Bottom Type Detection</i>	
Moniteq Ltd., Concord, Ontario	149,039
<i>Aerial Photographic Survey and Mapping of North Coast of Vancouver Island</i>	
McElhanney Group Ltd., Vancouver, B.C.	19,306
<i>Development and Provision of Long Range Capabilities to Existing Argo and Hi-Fix Equipment</i>	
McElhanney Group Ltd., Vancouver, B.C.	244,929
<i>Preparation of Active Drifter for Offshore Tests</i>	
Oceanetic Measurements Ltd., Victoria, B.C.	9,960
<i>Field Test of Offshore Active Drifter</i>	
Oceanetic Measurements Ltd., Victoria, B.C.	6,104
<i>Analysis of Satellite Tracked Drifter Data for the B.C. Coast</i>	
Odysseas Ocean Sciences Ltd., North Saanich, B.C.	3,120
<i>Analysis of Satellite Tracked Drifter Data for the West Coast of the United States</i>	
Odysseas Ocean Sciences Ltd., North Saanich, B.C.	2,925
<i>Investigation of Hydro-Acoustical Estimate of the Under Ice Morphology in the Arctic Ocean</i>	
Odysseas Ocean Sciences Ltd., North Saanich, B.C.	4,485
<i>Survey of Acoustic Profiling of an Arctic Ice Keel, Phase II</i>	
Offshore Survey and Positioning Services Ltd., North Vancouver, B.C.	\$ 36,040
<i>Implementation of Tropical Ocean-Global Atmosphere (TOGA) Observing Systems</i>	
Pacific Ocean Sciences Ltd., Burnaby, B.C.	40,400
<i>Data Interception of Ships-of-Opportunity</i>	
Pacific Ocean Sciences Ltd., Burnaby, B.C.	1,320
<i>Observations of Tides in the N.W. Passage</i>	
Pacific Ocean Sciences Ltd., Burnaby, B.C.	24,948
<i>Study of Numerical Prediction of Wind Generated Waves in the Coastal Sea Between Queen Charlotte Islands and the Mainland Coast of British Columbia</i>	
Pacific Ocean Sciences Ltd., Burnaby, B.C.	15,000
<i>To Supply an Enhanced HAL System</i>	
Quester Tangent Corp., Victoria, B.C.	50,920
<i>To Supply 5 X 512K Byte Bubble Cartridges for ISAH</i>	
Quester Tangent Corp., Victoria, B.C.	29,375
<i>Preparation of a Report on Pacific Transportation of Heat and Salt Paths Planning Meeting</i>	
S & B Research, Saanichton, B.C.	1,440
<i>Evaluation of Impact of New Observing Systems on Severe Sea State Warnings for the B.C. Coast</i>	
Seaconsult Marine Research Ltd., Vancouver, B.C.	119,819
<i>Study to Develop a SAR Procedure for Hazardous Waters</i>	
Seaconsult Marine Research Ltd., Vancouver, B.C.	165,000
<i>Evaluation of Tsunami Levels Along the B.C. Coastline</i>	
Seaconsult Marine Research Ltd., Vancouver, B.C.	242,000
<i>Analysis of Summary Statistics from West Coast Ships-of-Opportunity</i>	
Seakem Oceanography Ltd., Sidney, B.C.	11,123
<i>Inventory of Chemical Oceanography Data for the Sverdrup River Basin</i>	
Seakem Oceanography Ltd., Sidney, B.C.	44,975
<i>Study of Partitioning of Cadmium and Lead Between False Creek Dredge Spoils and Seawater</i>	
Seakem Oceanography Ltd., Sidney, B.C.	102,469

<i>Interpretation of Hydrographic Data in the North West Passage</i>	Seakem Oceanography Ltd., Sidney, B.C.	\$ 18,027
<i>Analysis of Marine Air Samples from Land Stations and Ocean Cruises</i>	Seakem Oceanography Ltd., Sidney, B.C.	22,970
<i>Analysis of Dissolved Nutrients in Seawater and Artificial Sea Water</i>	Seakem Oceanography Ltd., Sidney, B.C.	9,400
<i>Feasibility Study of the Development of a Deep Oceanic Drifter</i>	Seastar Instruments, Sidney, B.C.	9,829
<i>Testing and Evaluation of a Novel Acoustic Release</i>	Seastar Instruments, Sidney, B.C.	86,490
<i>Development of a Fibre Optic Dissolved Oxygen Sensor</i>	Seastar Instruments, Sidney, B.C.	227,955
<i>Development of an Intelligent Serial Interface Board for a Miniranger III Positioning System</i>	Seastar Instruments, Sidney, B.C.	7,987
<i>Develop and Test a Computer Model for Simulating the Doppler Spectrum of Acoustic Waves Backscattered from the Ocean Surface</i>	SH Scientific Computing Services, Vancouver, B.C.	6,040
<i>Calibration, Installation and Testing of CTD/Rosette System on CSS Parizeau</i>	SH Scientific Computing Services, Vancouver, B.C.	1,583
<i>Analysis of Hecate Strait Bio-oceanographic Data</i>	SH Scientific Computing Services, Vancouver, B.C.	3,995
<i>Design and Develop Computerised Databases for Co-ordination and Management of Job Development Programs</i>	Soft-Tech Development Corp., Victoria, B.C. . . .	3,998
<i>Preparation of Geostrophic Current Mapping Programmes</i>	M.D. Speedie, Victoria, B.C.	1,300
<i>Preparation of Turbulence Profiler FLY II for Field Use</i>	Sy-Tech Research Ltd., Sidney, B.C.	5,190
<i>Data Acquisition System for Pisces IV</i>	Sy-Tech Research Ltd., Sidney, B.C.	18,783
<i>Preparation of Planning Chart of the Beaufort Sea</i>	Terra Surveys, North Saanich, B.C.	2,500
<i>Development of Correlation of Uni-polar Data Pulses</i>	Thalassic Data Ltd., Sidney, B.C.	\$ 14,457
<i>Co-ordination of 3 Consecutive International Tsunami Meetings</i>	Tide and Tsunami Services Ltd., Saltspring Island, B.C.	13,634
<i>Numerical Modelling Studies of the Strait of Georgia (Part VII)</i>	University of British Columbia, (Dr. Burling), Vancouver, B.C.	26,000
<i>Continuation of Study of Comparison of Freon Techniques in Seawater</i>	University of Victoria, Victoria, B.C.	2,000
<i>Development of a Geo-thermal Model of Freon Transfer from the Atmosphere into the Ocean</i>	University of Victoria, Victoria, B.C.	10,354
<i>Provision of Backscatter and Ambient Sound Data in the Atlantic Ocean</i>	S. Vagle, Brentwood Bay, B.C.	1,990
<i>A Laboratory Investigation of Salinity Driven Slope Convection</i>	B. VanHardenberg, Sidney, B.C.	8,500
<i>Preliminary Testing of Small Scale Wave Tank</i>	B. VanHardenberg, Sidney, B.C.	1,350
<i>Development of a Launch Engine Information System</i>	Vargas Consulting, Victoria, B.C.	11,585
<i>Time Series Analysis of Scintillation Data</i>	J. Verrall, Victoria, B.C.	1,080
<i>Modifications to BERT 101 Range and Bearing Acquisition System</i>	Walker Industrial Computing Ltd., North Saanich, B.C.	8,350
<i>Identify and Enumerate Phytoplankton Collection by the Ship-of-Opportunity Project</i>	R. Watters, Guildford, Surrey, England	2,000
<i>Literature Review on Carbon Cycling Models</i>	Western Ecological Services Ltd., Victoria, B.C. . .	10,135
<i>Development of a Biological Pump Model of CO₂ Removal from Surface Sub-Arctic Waters into Deep-Water Storage Via Detritus Fluxes of Fecal Pellets and Calcareous Shells</i>	Western Ecological Services Ltd., Victoria, B.C. . .	4,280
<i>Prepare Reports on CO₂ Data from Ocean Station Papa and Ships-of-Opportunity Programmes</i>	Western Ecological Services Ltd., Victoria, B.C. . .	10,330

<i>Modelling and Analysis of Data from West Coast of Queen Charlotte Islands, Dixon Entrance and Hecate Strait</i>	
R. Wilson, North Saanich, B.C.	\$ 18,921
<i>Sorting of Benthic Samples Fixed in Formalin</i>	
R. Woods, Sidney, B.C.	750
<i>Organize West Coast Ocean Dumping Workshop 1985 and Prepare Workshop Proceedings for Publication</i>	
S.M. Woods, Sidney, B.C.	4,010
<i>Study of the Variability of the Total Ocean to Atmosphere Heat Exchange</i>	
Yong Ping Zhao, Sidney, B.C.	12,000
B. Department of Energy, Mines and Resources	
<i>Preparation of Illustrations, Pacific Geoscience Centre</i>	
L. Bedard, Victoria, B.C.	\$ 25,000.00
<i>Picking and Sorting of Microfossils</i>	
Cameron Biostratigraphic Services, Victoria, B.C.	6,000.00
<i>Preparation of a Manuscript on the Early and Middle Jurassic Radiolarian Biostratigraphy of the Queen Charlotte Islands</i>	
E.S. Carter, consultant, Vancouver, B.C.	4,000.00
<i>Preparation of a Report on Biostratigraphy on the Basis of Fossil Radiolaria from Selected Mesozoic Rocks of the Insular Belt</i>	
E.S. Carter, consultant, Vancouver, B.C.	6,000.00
<i>Operation and Maintenance of a Regional Seismic Station in Prince Rupert and Telemetered Stations in the Queen Charlotte Islands</i>	
B. Chandra & Associates Ltd., Vancouver, B.C.	8,025.00
<i>Investigation of Geohazards to Development on the Continental Shelf off Western Canada</i>	
K. Conway, Victoria, B.C.	7,350.00
<i>The Study of Upper Crustal Structure Below Hecate Strait from Airgun/Ocean Bottom Seismograph Data</i>	
Dr. R.M. Clowes, Dept. Geophys. & Astron., U.B.C.	14,833.00
<i>Acquisition of Crustal Refraction Data on Juan de Fuca Ridge</i>	
Dr. R.M. Clowes, Dept. Geophys. & Astron., U.B.C.	\$ 23,408.00
<i>Seismographic Data Collected at Selected Sites on the West Coast of British Columbia</i>	
Dr. R.M. Ellis, Dept. Geophys. & Astron., U.B.C.	10,975.00
<i>Earthquake Studies in the Beaufort Sea</i>	
Dr. G.D. Garland, U. of Toronto.	14,710.00
<i>Acquisition, Compilation and Analysis of Marine Geological and Geophysical Data from the Continental Shelf and Adjacent Offshore Regions of Western Canada</i>	
Geomartec Services, Brentwood Bay, B.C.	18,375.00
<i>Offshore Multichannel Seismic Profiling</i>	
Geophoto Ltd., Calgary, Alta. ....	.630,000.00
<i>SeaMARC II Survey of the Northern Juan de Fuca Ridge System and Vancouver Island Continental Slope</i>	
Hawaii Institute of Geophysics, Honolulu, Hawaii.	437,533.00 (U.S.)
<i>Radiocarbon Dating of Shell Samples</i>	
Isotrace Laboratory (Univ. of Toronto)	5,184.00
<i>Marine Survey of the Surficial Geology and Morphology of Northwestern Graham Island</i>	
Offshore Survey and Positioning Services Ltd., North Vancouver, B.C.	54,600.00
<i>Supply of Electronics for Telemetering Heat Probe</i>	
Polar Tech Ltd., Sidney, B.C.	75,684.00
<i>Compilation of a Digital Terrain File in Selected Areas of the Western Cordillera</i>	
SIAL, Compagnie Internationale de Géophysique Inc., Dorval, Quebec. ....	.102,037.00
<i>Precise Gravity Survey of Selected Sites on Vancouver Island</i>	
SIAL, Compagnie Internationale Géophysique Inc., Dorval, Quebec.	27,772.00
<i>A Comparison of LANDSAT 5 and Airborne Multispectral System for Coastal Remote Sensing</i>	
Simon Fraser University (Geography Dept.). .	6,500.00
<i>Computer Based Mapping of Coastal Geomorphology and Lidimentology</i>	
E. Strong, Calgary, Alta.	6,000.00

Lithoprobe Profiles One and Three 1985 Field Component-Geological Mapping
A. Sutherland Brown, Victoria, B.C. \$ 55,000.00

Grain Size Analysis of Sediment Samples from the West Coast of Canada
Thurber Consultants Ltd., Victoria, B.C. \$ 27,126.00

Awards:

Canadian Society of Petroleum Geologists Medal of Merit, 1983; presented in February, 1985 to Dr. C.J. Yorath.

APPENDIX II

Publications, 1985

(1) Canadian Data Report of Hydrography and Ocean Sciences

BIRCH, J.R., E.C. LUSCOMBE, D.B. FISSEL and L.F. GIOVANDO. *West Coast Data Inventory and Appraisal. Dixon Entrance, Hecate Strait, Queen Charlotte Sound and Adjoining B.C. Coastal Waters: Physical Oceanography—Temperature, Salinity, Currents, Water Levels and Waves, 1903 through 1984.* No. 37, Vol. 1; Part 1, 310 pp, Part 2, 271 pp.

BUCKINGHAM, W.R., R.A. LAKE and H. MELLING. *Temperature and Salinity Measurements in the Northwest Passage, in March-April, 1982.* Vol. 1, No. 39, 371 pp.

DENMAN, K., R. FORBES, D. MACKAS, S. HILL and H. SEFTON. *Ocean Ecology Data Report: British Columbia Coastal Waters, 29 June-10 July, 1983.* No. 36, 77 pp.

GIOVANDO, L.F. *Observations of Seawater Temperature and Salinity at British Columbia Shore Stations, 1983.* No. 30, 112 pp.

GIOVANDO, L.F. *Observations of Seawater Temperature and Salinity at British Columbia Shore Stations, 1984.* No. 41, 105 pp.

SACKMAN, T. and B.D. SMILEY. *Arctic Industrial Activities Compilation. Sverdrup Basin: Hydrocarbon Exploration 1974 to 1984.* No. 32, Vol. 2, 194 pp.

TABATA, S. and J.L. PEART. *Statistics of Oceanographic Data Based on Hydrographic/STD Casts Made at Ocean Station P during August 1956 through June 1981.* No. 31, 140 pp.

- TAYLOR, D.A., M.G. REED, B.D. SMILEY and G.S. FLOYD. *Arctic Industrial Activities Compilation. Beaufort Sea: Marine Dredging Activities 1959 to 1982*. No. 32, Vol. 1, 205 pp.
- THOMSON, R.E., W.R. CRAWFORD, H.J. FREELAND and W.S. HUGGETT. *Low-Pass Filtered Current Meter Records for the West Coast of Vancouver Island: Coastal Oceanic Dynamics Experiment, 1979-1981*. No. 40, 108 pp.

(2) Canadian Technical Report of Hydrography and Ocean Sciences

- RAMSDEN, D., D. WHITFIELD and G. HOLLOWAY. *Spectral Transform Simulations of Turbulent Flows, with Geophysical Applications*. No. 57, 59 pp.
- VERMEER, K. *A Five-Year Summary (1978-1982) of the Nestling Diet of Cassin's Auklets in British Columbia*. No. 56, 18 pp.
- VERMEER, K. and L. RANKIN. *Pelagic Seabird Population in Dixon Entrance*. No. 65, 25 pp.

(3) Canadian Contractor Report of Hydrography and Ocean Sciences

- ANDERSON, E.P. *Effects of Suspended Tailing from the AMAX/Kitsault Mine on the Predation Rates of the Marine Zooplankters Euchaeta elongata and Euphausia pacifica*. No. 21, 26 pp.
- WOODS, S.M., (ed.). *Report on Ocean Dumping R&D Pacific Region. Department of Fisheries and Oceans 1983-84*. No. 20, 62 pp.

(A) Department of Fisheries and Oceans

- ARMI, L. and D.M. FARMER. 1985. The internal hydraulics of Gibralter Strait and associated sills and narrows. *Oceanologica Acta*, **8**: 37-46.
- BENNETT, A.F. and K.L. DENMAN. 1985. Phytoplankton patchiness: inferences from particle statistics. *J. Mar. Res.*, **43**: 307-335.
- BENNETT, A.F. 1985. Absolute velocity and the thermodynamics of seawater. *Ocean Modelling*, Oxford University/U.S. Office of Naval Research, **62**: 1-3.

- BORSTAD, G.A., J.F.R. GOWER, H.R. EDEL and A.B. HOLLINGER. 1985. Analysis of test and flight data from the Fluorescence Line Imager. *Can. Spec. Publ. of Fisheries and Aquatic Sciences*, No. 83, 38 pp.
- BRINKHURST, R.O. 1985. A further contribution to the taxonomy of the genus *Tubificoides* Lastockin (Oligochaeta: Tubificidae). *Can. J. Zool.*, **63**: 400-410.
- BRINKHURST, R.O. 1985. The generic and subfamilial classification of the Naididae (Annelida: Oligochaeta). *Proc. Biol. Soc. Wash.*, **98**: 470-475.
- BRINKHURST, R.O. 1985. *Varichaetadrilus minutus* (Brinkhurst, 1965) new combination for *Psammoryctides* (?) *minutus* (Oligochaeta: Tubificidae). *Proc. Biol. Soc. Wash.*, **98(3)**: 655-656.
- BRINKHURST, R.O. 1985. The three-fold path. In: *Proceedings of the Tenth Annual Aquatic Toxicity Workshop, Nov. 7-10, 1983, Halifax, Nova Scotia*, P.G. Wells and R.F. Addison (eds.), *Can. Tech. Rept. Fish. and Aquat. Sci.*, **1368**: 3-9.
- BRINKHURST, R.O. 1985. Museum collections and aquatic invertebrate environmental research. In: *Museum Collections: Their Roles and Future in Biological Research*, Miller, E.H. (ed.), *British Columbia Provincial Museum Occasional Paper* 25.
- BRINKHURST, R.O. 1985. Three contributions to "New Canadian Encyclopedia"—Leech, Annelids, Earthworm. *New Canadiana Encyclopedia Publishing Ltd.*, Edmonton.
- BRINKHURST, R.O. 1986. A guide to the aquatic Oligochaeta of North America. *Canadian Special Publication of Fisheries and Aquatic Sciences* **84**: 259 pp.
- BRINKHURST, R.O. and M.T. BARBOUR 1985. A new species of *Aulodrilus* Bretscher (Oligochaeta, Tubificidae) from North America. *Proc. Biol. Soc. Wash.*, **98**: 931-934.
- BRINKHURST, R.O. and K.A. COATES. 1985. The genus *Paranais* (Oligochaeta, Naididae) in North America. *Proc. Biol. Soc. Wash.*, **98**: 303-313.
- BRINKHURST, R.O. and R.J. DIAZ. 1985. *Isochaetides columbiensis* new species (Oligochaeta, Tubificidae) from the Columbia River, Oregon. *Proc. Biol. Soc. Wash.*, **98**: 949-953.
- BURD, B.J. and R.O. BRINKHURST. 1985. The effect of oxygen depletion on the galatheid crab (*Munida quadrispina*) in Saanich Inlet, British Columbia. In: *Marine Biology of Polar Regions and Effects of Stress on Marine Organisms*, J.S. Gray, and M.E. Christiansen, (eds.). J. Wiley and Sons, Chichester, pp 435-444.
- COSSON-MANNEVY, M.A., C.S. WONG and W.J. RETNEY. 1985. Putative neoplastic disorders in mussels (*Mytilus edulis*) from southern Vancouver Island waters, B.C. *J. Invert. Pathology*, **44**: 151-160.
- CRAWFORD, W.R. 1985. Book review of "Hydrography for the Surveyor and Engineer" by A.E. Ingham. *Marine Geodesy*, **4**: 481-482.

- DENMAN, K.L. and H.J. FREELAND. 1985. Correlation scales, objective mapping and a statistical test of geostrophy on a continental shelf. *J. Mar. Res.*, **43**(3): 517-539.
- DENMAN, K.L. et al. 1985. Technological developments to implement theory into biological oceanography. In: *Ecosystem Theory for Biological Oceanography*, R.E. Ulanowicz and T. Platt, (eds.). *Can. Bull. Fish. Aquat. Sci.* **213**: 254-258.
- EL-SABH, M.I., B. TESSIER and T.S. MURTY. 1985. Fractal dimension and length of an irregular coastline. *Science of Tsunami Hazards*, **3**(1): 41-44.
- FARMER, D.M. and R.A. DENTON. 1985. Hydraulic control of flow over the sill in Observatory Inlet. *J. Geophys. Res.*, **90**(C5): 9051-9068.
- FORBES, J.R. 1985. Book review of "Marine and Coastal Systems of the Quoddy Region, New Brunswick", M.L. Thomas (ed.). *Can. Spec. Publ. Fish. Aquat. Sci.*, 64. In: *Can. Field-Nat.*, **99**: 127-128.
- FORBES, J.R. 1985. Book review of "A Manual of Chemical and Biological Methods for Seawater Analysis" by T.R. Parsons, Y. Maita and C.M. Lalli, Pergamon Press. In: *Can. J. Fish. Aquat. Sci.*, **42**: 624.
- FREELAND, H.J., J.A. CHURCH, R.L. SMITH and F.M. BOLAND. 1985. Current meter data from the Australian Coastal Experiment. *CSIRO Marine Labs, Data Report* 169.
- GARGETT, A.E. 1985. Evolution of scalar spectra with the decay of turbulence in a stratified fluid. *J. Fluid Mech.*, **159**: 379-407.
- GIANI, N.E., E. MARTINEZ-ANSEMIL and R.O. BRINKHURST. 1984. Revision du statut taxonomique des Aulodrilinae (Tubificidae, Oligochaeta). *Bull. Soc. Hist. Nat. Toulouse*, **120**: 17-22.
- GONZALES, F.I., E.D. COKELET, J.F.R. GOWER and M.R. MULHERN. 1985. SLAR and *in situ* observations of wave current interaction on the Columbia River bar. In: *The Ocean Surface: Wave Breaking, Turbulent Mixing and Radio Probing*, Y. Toba and H. Mitsuyasu (eds.), D. Reidel, pp 303-310.
- GOWER, J.F.R. 1985. Reduction of the effect of clouds on satellite thermal imagery. *Int. J. Remote Sensing*, **6**: 1419-1434.
- GREISMAN, P. and W.R. CRAWFORD. 1985. First current survey using Loran-C drifting buoys. *Maritime Industries*, **1**(1): 22-23.
- HILL, S.H., M.R. ABBOTT and K.L. DENMAN. 1985. A computer-controlled turbidostat for the culture of planktonic algae. *Can. J. Fish. Aquat. Sci.*, **42**: 744-753.
- KEELING, C.D., T.P. WHORF, C.S. WONG and R.D. BELLEGAY. 1985. The concentration of atmospheric CO_2 at Ocean Weather Station P from 1969 to 1981. *J. Geophys. Res.*, **90**: 10,511-10,528.

- KOWALIK, Z. and T.S. MURTY. 1985. Computation of tsunami amplitudes resulting from a predicted major earthquake in the Shumagin seismic gap. *Geophysical Research Letters*, **11(12)**: 1243-1246.
- KUNDU, P.K. and R.E. THOMSON. 1985. Inertial oscillations due to a moving front. *J. Phys. Oceanogr.*, **15(8)**: 1076-1084.
- LEBLOND, P.H., B.M. HICKEY and R.E. THOMSON. 1985. Runoff driven coastal flow off British Columbia. In: *Proc. of NATO Workshop on the Influence of Fresh Water on the Sea, Bobo, Norway, May 20-26, 1985*.
- LEE, K., C.S. WONG, W.J. CRETNEY, F.A. WHITNEY, T.R. PARSONS, C.M. LALLI and J. WU. 1985. Microbial response to crude oil and Corexit 9527: SEAFLUXES enclosure study. *Microbial Ecology*, **11**: 337-351.
- LEWIS, E.L. 1985. Calibration of CTD sensors. In: *Evaluation, Comparison and Calibration of Oceanographic Instruments*, Soc. for Underwater Tech., Graham and Trotman Ltd., London.
- LEWIS, E.L. 1985. The ice pump, a mechanism for ice-shelf melting. In: *Glaciers, Ice Sheets and Sea Level: Effects of a CO₂-induced Climatic Change*, Nat. Academy Press, Washington, D.C., pp 275-278.
- LEWIS, E.L. and R.G. PERKIN. 1985. The winter oceanography of McMurdo Sound Antarctica. In: *Oceanology of Antarctic Continental Shelf*, Jacobs (ed.), Antarctic Research Series, Am. Geophys. Union, Washington, D.C., **43**: 145-165.
- MACDONALD, R.W. and M. O'BRIEN. 1985. Extending the use of certified reference sediments for assessment of accuracy in determinations of trace metals. *Anal. Chem. Acta*, **177**: 81-91.
- MACKAS, D.L. 1985. Book review of "Methods in Marine Zooplankton Ecology" by M. Omori and T. Ikeda, Wiley-Interscience, New York, N.Y 1984. In: *Can. J. Fish. and Aquat. Sci.*, **6**: 1232..
- MACKAS, D.L. 1985. Report on the Office of Naval Research Bioacoustic Sampling Workshop, Ed. Hartwig (ed.), pp. 57-60.
- MACKAS, D.L., K.L. DENMAN and M.R. ABBOTT. 1985. Plankton patchiness: biology in the physical vernacular. *Bull. Mar. Sci.*, **37(2)**: 652-674.
- MACKAS, D.L. and E.P. ANDERSON. 1985. Small scale zooplankton variability in the northern British Columbia fjord system. *Estuar. Coastal Shelf Sci.*, **21**.
- MCDONALD, D. and K.A. CZOTTER. 1985. The hydrographic contouring system—practical experiences. *Lighthouse*, **31**, May 1985.
- MIDDLETON, J.H. and R.E. THOMSON. 1985. Steady wind-driven coastal circulation beta-plane. *J. Phys. Oceanogr.*, **15(12)**: 1809-1817.

- MURTY, T.S. and G. HOLLOWAY. 1985. Influence of marginal ice cover on storm surges. *J. Waterway, Port, Coastal and Ocean Engineering*, **111**: 329-336.
- MURTY, T.S. and M.I. EL-SABH. 1985. The age of tides. *Oceanography and Marine Biology Annual Reviews*, **23**: 11-103.
- MURTY, T.S. 1985. Modification of hydrographic characteristics, tides and normal modes by ice cover. *Marine Geodesy*, **9(4)**: 451-468.
- MURTY, T.S. and M.I. EL-SABH. 1985. Gravitational oscillations in a rotating paraboloidal basin: a classical problem revisited. *Bull. Nat. Inst. Oceanography*, **180(2)**: 99-127.
- MURTY, T.S. and M.I. EL-SABH. 1985. Simulation of gyres in the Gulf of St. Lawrence and St. Lawrence Estuary, modelling simulation and control. *A.M.S.C., Series C*, **2(3)**: 9-27.
- NEMEC, A.F.L. and J.M. NEMEC. 1985. A test of significance for periods derived using phase-dispersion minimization techniques. *Astronomical Journal*, **90**: p. 2317.
- NEMEC, A.F.L. and J.M. NEMEC. 1985. Statistical properties of phase-dispersion period minimization finding techniques. *Bull. Am. Astron Soc.*, **17**: p. 597.
- PERCY, R., B.D. SMILEY and T. MULLIN. 1985. *Fishes, Invertebrates and Marine Plants: The Beaufort Sea and the Search for Oil*. Beaufort Sea Project Overview Report Series, Volume 5. Institute of Ocean Sciences, Sidney, B.C., 167 pp.
- SANDILANDS, R.W. 1985. Tall ships—tall men. *The Nova Scotian Surveyor*, January 1985, pp. 20-28.
- SMY, P.R., R.M. CLEMENTS and D.R. TOPHAM. 1985. Efficiency and erosion of plasma jet igniter—variations with voltage. *Combustion Science and Technology*, **42**: 317-324.
- STEPHENSON, F.E. and D.J. GREGSON. 1985. Meteor Burst tsunami warning systems. *Proc. of the International Tsunami Symposium, IUGG, August 6-9, 1985*, pp. 134-139.
- STUCCHI, D.J. 1985. The tidal jet in Rupert-Holberg Inlet, B.C. *Atmosphere-Ocean*, **23(2)**: 118-136.
- TABATA, S. 1985. El Nino effects along and off the Pacific coast of Canada during 1982-83. In: *El Nino North, Nino Effects in the Eastern Subarctic Pacific Ocean*. W.S. Wooster and D.L. Fluharty (eds.), *Washington Sea Grant Program, University of Washington, Seattle*, 312 pp, 85-96.
- TABATA, S. 1985. Specific problems in maintaining time series observations. In: *Time Series of Ocean Measurements, Intergovernmental Oceanogr. Comm. Technical Series, UNESCO*, **2**: 55-60.
- THOMPSON, J.A.J., M.G. SHEFFER, R.C. PIERCE, Y.K. CHAU, J.J. COONEY, W.R. CULLEN and R.J. MAGUIRE. 1985. Organotin compounds in the aquatic environment. Scientific criteria for assessing their effects on environmental quality. *National Research Council of Canada*, No. 22494, 284 pp.

- THOMSON, R.E. and J.F.R. GOWER. 1985. A wind-induced mesoscale eddy over the Vancouver Island continental slope. *J. Geophys. Res.*, **90**: 8981-8993.
- THOMSON, R.E., S. TABATA and D. RAMSDEN. 1985. Comparison of sea level variability of the Caribbean and Pacific coasts of the Panama Canal. *IOC. Time Series of Ocean Measurements*. Vol. 2-1984 IOC Tech. Ser. **30**: UNESCO, 1985.
- WONG, C.S., R.D. BELLEGAY, G.E. SMITH, J.S. PAGE and Y.-H. CHAN. 1985. Seasonal changes in oceanic pCO₂ in surface Pacific Ocean. In: *Proc. Atmospheric CO₂, its Sources, Sinks and Global Transport, IAMAP Conference, Switzerland, September 2-6, 1985*, pp. 189-196.
- WONG, C.S., J.S. PAGE, R.D. BELLEGAY, K. ISEKI and Y.-H. CHAN. 1985. A biological pump model of CO₂ removal from surface subarctic waters into deep-water storage via detritus fluxes of fecal pellets and calcareous shells. In: *Proc. Atmospheric CO₂, its Sources, Sinks and Global Transport, IAMAP Conference, Switzerland, September 2-6, 1985*, pp. 216-223.
- WOODWARD, M.J. 1985. An evaluation of the RCM4 current meter in the wave zone. In: *Proc. Oceans '85*, pp. 755-762.

(B) Department of Environment

- MCBEAN, G.A. and T.S. MURTY. 1985. A marked mesoscale pressure-induced wind variation. *Boundary-Layer Meteorology*, **31**: 209-216.
- MCBEAN, G.A. and M. MIYAKE. 1985. Response of the upper ocean to atmospheric forcing. In: *The Ocean Surface*, Y. Toba and H. Mitsuyasu (eds.), D. Reidel, pp. 527-524.
- VERMEER, K. 1985. The diet and food consumption of nesting Cassin's Auklets during summer, and a comparison with other plankton-feeding alcids. *Murrelet*, **65**: 65-77.
- VERMEER, K., J.B. FULTON and S.G. SEALY. 1985. Differential use of zooplankton by Ancient Murrelets and Cassin's Auklets in the Queen Charlotte Islands. *J. Plankton Res.*, **7**: 443-459.
- VERMEER, K. and K. DEVITO. 1985. Size, caloric content, and associated prey fishes in meals of nestling Rhinoceros Auklets. *Murrelet*, **65**.

(C) Department of Energy, Mines and Resources

- ADSHEAD, J.D., B.D. BORNHOLD and E.E. DAVIS. 1985. Geochemistry of deposits from mound and collapse structures near Juan de Fuca ridge. *EOS*: 926.

- ARMSTRONG, R.L., J.W.H. MONGER and E. IRVING. 1985. Age of magnetization of the Axelgold Gabbro, north-central British Columbia. *Can. J. Earth Sci.*, **22**: 1217-1222.
- BASHAM, P.W., D.H. WEICHERT, F.M. ANGLIN and M.J. BERRY. 1985. New probabilistic strong seismic ground motion maps of Canada. *Bull. Seism. Soc. of America*, **75**: 563-595.
- BENTKOWSKI, W.H. and T.J. LEWIS. 1985. Preliminary results from shallow drilling in the Anahim Volcanic Belt, B.C. *Earth Physics Branch Open File Report 85-9*.
- BORNHOLD, B.D., and P. GIRESSE. 1985. Conditions de glauconitisation profondes et abondantes sur une marge active de l'Océan Pacifique Nord (Vancouver). *Competes Rendus de l'Acad. Sci. (Paris)*, t. 300, Série II, No. 11.
- BORNHOLD, B.D., and P. GIRESSE. 1985. Glauconitic sediments on the continental shelf off Vancouver Island, British Columbia. *Canada. Jour. Sediment. Petrol.*, v. **55**: 653-664.
- BORNHOLD, B.D. and R. GOOD. 1985. Marine survey methodology of the surficial geology and morphology of northwestern Graham Island. Underwater Mining Institute, Halifax, N.S., November 1985.
- BORNHOLD, B.D. and D.B. PRIOR. 1985. Geomorphology of slope instability features, Kitimat Arm, Squamish Harbour, and Britannia Beach, British Columbia. *14th Arctic Workshop, Nov. 6-8, Dartmouth, N.S.*
- BORNHOLD, B.D. and D.B. PRIOR. 1985. Geomorphology of a fiord-head submarine landslide, British Columbia. Abstr., *International Tsunami Symposium, Aug. 5-9, 1985, Victoria, British Columbia*.
- BORNHOLD, B.D., D.B. PRIOR and R.W. MACDONALD. 1985. Sedimentary processes in British Columbia fiords. *8th International Estuarine Research Conference, Durham, N.H., Estuaries*, v. 8, p. 119A.
- CAMERON, B.E.B. and H.W. TIPPER. 1985. Jurassic Stratigraphy of the Queen Charlotte Islands. *G.S.C. Bulletin 365*.
- CHILDERHOSE, C., E.E. DAVIS and G.C. ROGERS. 1985. The Juan de Fuca Ridge. *EMR Public Information Pamphlet*.
- CURRIE, R.G., E.E. DAVIS and B.S. SAWYER. 1985. Juan de Fuca Ridge Atlas: Preliminary SEABEAM bathymetry. *Earth Physics Branch Open File Reports 85-1 and 85-18*.
- DAVIS, E.E. 1985. The application of swath bathymetric and acoustic image mapping to contemporary problems in marine geoscience. *Ocean Science and Surveys Conference Program with Abstracts*.
- DAVIS, E.E., R.G. CURRIE and B.S. SAWYER. 1985. Juan de Fuca Ridge Atlas: Regional SeaMARC II acoustic image mosaics and SEABEAM bathymetry. *Earth Physics Branch Open File Report 85-2*.

- DAVIS, E.E., R.G. CURRIE, R.P. RIDDIHOUGH and B.S. SAWYER. 1985. A new look at the Juan de Fuca ridge: high resolution bathymetry and side-scan acoustic imagery. *GEOS*, **14**: 10-15.
- DAVIS, E.E. and J.L. KARSTEN. 1985. An explanation for the asymmetric distribution of seamounts on the flanks of the Juan de Fuca ridge. *EOS*, **66**: 403.
- DELAURIER, J.M., R.D. KURTZ and J.C. GUPTA. 1985. A magnetotelluric survey over the subduction zone under Vancouver Island, B.C. *Abstract, 1985 GSEG/CGU Convention, Geophysics*, **50, 8**: 1370-1371.
- DRYSDALE, J.A., R.B. HORNER, R.J. WETMILLER, A.E. STEVENS, G.C. ROGERS and P.W. BASHAM. 1985. Canadian Earthquakes 1982. *Seism. Series Earth Physics Branch, No. 92*.
- DUGGAN, D.M. and J.L. LUTERNAUER. 1985. Development induced tidal flat erosion, Fraser River Delta, B.C.: Final report. In: *Current Research, Part A; G.S.C. Paper 85-1A*, p. 317-326.
- EDWARDS, R.N., L.K. LAW, P.A. WOLFGRAM, D.C. NOBES, M.N. BONE, D.F. TRIGG and J.M. DELAURIER. 1985. First results of the MOSES experiment: Sea sediment conductivity and thickness determination, Bute Inlet, British Columbia, by magnetometric offshore electrical sounding. *Geophysics*, **50**: 153-160. Contr. No. 1133.
- FLORES, C., R.D. KURTZ and J.M. DELAURIER. 1985. Magnetotelluric exploration in the Meager Mountain geothermal area, Canada. *Acta Geodaet., Geophys. et Montanist. Hung.*, **20, 1**: 165-171.
- GREEN, A.G., M.J. BERRY, C. SPENCER, E.R. KANASEWICH, S. CHIU, R.M. CLOWES, C.J. YORATH, D.B. STEWART, J.D. UNGER and W.H. POOLE. 1985. Recent Seismic reflection studies in Canada. In: *Deep structure of the continental crust: Results from reflection seismology*, M. Barazangi and L. Brown (eds.), *AGU Geodynamics series*.
- HAMILTON, T.S. and S.O. WIGEN. 1985. The foreslope hills of the Fraser delta: implications for tsunamis in Georgia Strait—A summary. In: *Proceedings of the International Tsunami Symposium 1985*, p. 110-118.
- IRVING, E., G.J. WOODSWORTH, P.J. WYNNE and A. MORRISON. 1985. Paleomagnetic evidence for displacement from the south of the Coast Plutonic Complex, British Columbia. *Can. J. Earth Sci.*, **22**: 1217-1222.
- IRVING, E. and J.L. LUTERNAUER. 1985. On correcting inclination error in recent sediments. In: *Program with abstracts, meeting, Pacific Northwest section of AGU, Vancouver*.
- IRVING, E. and D.F. STRONG. 1985. Paleomagnetism of rocks from Burin Peninsula, Newfoundland: hypothesis of Late Paleozoic displacement of Acadia criticized. *J. Geophys. Res.*, **90**: 1949-1962.

- IRVING, E. 1985. Whence British Columbia? *Nature*, **314**: 673-674.
- LEWIS, T.J., A.M. JESSOP and A.S. JUDGE. 1985. Heat flux measurements in southwestern British Columbia: the thermal consequences of plate tectonics. *Can. J. Earth Sci.* **22**: 1262-1273.
- LEWIS, T.J., W.H. BENTKOWSKI, E.E. DAVIS, R.D. HYNDMAN, J.A. WRIGHT and J.G. SOUTHER. 1985. A heat-flux profile across southern Vancouver Island to the Garibaldi volcanic belt. *GAC/CGU Program with Abstracts, Lithoprobe Publication No. 10*.
- LUTERNAUER, J.L. 1985. Johnstone Strait, British Columbia—surficial sediment and sand wave distribution and location of other types of data collected by the G.S.C. G.S.C. *Open File 1125*.
- LUTERNAUER, J.L., K.W. CONWAY and J.J. CLAQUE. 1985. Timing and extent of Late Wisconsinan glaciation on the central continental shelf off western Canada. In: *Program with Abstracts, CANQUA Symposium on the paleo-environmental reconstruction of the Late Wisconsinan deglaciation and the Holocene, Lethbridge, Alberta*, p. 41.
- MACDONALD, R., D. MACDONALD and B.D. BORNHOLD. 1984. The use of ^{210}Pb and sub-bottom profiling to study sedimentation in the Kitimat fjord system. *Abstr. Annual Congress, Can. Met. and Ocean. Soc., Dalhousie Univ., May 29-June 1, 1984*.
- NOBES, D.C., H. VILLINGER, E.E. DAVIS and L.K. LAW. 1985. Prediction of bulk physical properties at depth for Middle Valley sediments, Juan de Fuca Ridge. *EOS, Trans. Am. Geophys. Un.*, **66**: 1361.
- PRIOR, D.B. and B.D. BORNHOLD. 1985. Contrasts in sediment mass transport and depositional processes in two British Columbia fiords. *14th Arctic Workshop, Nov. 6-8, Dartmouth, N.S.*
- REES, C.J., E. IRVING and R.L. BROWN. 1985. Secondary magnetization of Triassic-Jurassic volcaniclastic rocks of the Quesnel terrane, Quesnel Lake, B.C. *Geophys. Res. Lett.*, **12**: 498-501.
- ROBERTS, M.C., H.F.L. WILLIAMS, J.L. LUTERNAUER and B.E.B. CAMERON. 1985. Sedimentary framework of the Fraser River Delta, B.C.—preliminary field and laboratory results. In: *Current Research, Part A; G.S.C. Paper 85-1A*, p. 717-722.
- ROGERS, G.C. 1985. Juan de Fuca Plate Map—JFP12: Seismograph stations, Jan. 1, 1985. *Earth Physics Branch Open File 85-35*. Department of Energy, Mines and Resources, Canada.
- ROGERS, G.C. 1985. Variation in Cascade volcanism with margin orientation. *Geology*, **13**: 495-498.

- SUTHERLAND BROWN, A. and C.J. YORATH. 1985. Lithoprobe profile across southern Vancouver Island: Geology and tectonics. *Geological Society of America, Cordilleran Section Meeting, Field Guidebook*.
- SWEENEY, J.F. 1984. Arctic tectonics: what we know today. *GEOS*, **13**, 4, Dept. Energy, Mines & Resources, Ottawa, 8-10.
- SWEENEY, J.F. 1985. Comments about the age of the Canada Basin. *Tectonophysics*, **114**: 1-10.
- SWEENEY, J.F. 1985. Comments about the age of the Canada Basin. In: *Geophysics of the Polar Regions*, Elsevier, E.S. Husebye, G.C. Johnson and Y. Cristoffersen (editors), Amsterdam, 1-10.
- WEBER, J.R. and J.F. SWEENEY. 1985. Reinterpretation of morphology and crustal structure in central Arctic Basin. *J. Geophys. Res.*, **90**: 663-677.
- WEICHERT, D.H. 1985. New Brunswick strong ground motion records. *Physics of the Earth and Planetary Interiors*, **38**: 83-91.
- YORATH, C.J., A.G. GREEN, R.M. CLOWES, A. SUTHERLAND BROWN, M.T. BRANDON, E.R. KANASEWICH, R.D. HYNDMAN and C. SPENCER. 1985. Lithoprobe, southern Vancouver Island: Seismic reflection sees through Wrangellia to the Juan de Fuca plate. *Geology*, **13**: 759-762.
- YORATH, C.J., R.M. CLOWES, A.G. GREEN, A. SUTHERLAND BROWN, M.T. BRANDON, N.W.D. MASSEY, C. SPENCER, E.R. KANASEWICH and R.D. HYNDMAN. 1985. Lithoprobe Phase 1: southern Vancouver Island: Preliminary analyses of reflection seismic profiles and surface geological studies. In: *Current Research, Geological Survey of Canada, Paper 85-1A*, p. 543-554.
- YORATH, C.J., G.J. WOODSWORTH, R.P. RIDDIHOUGH, R.G. CURRIE, R.D. HYNDMAN, G.C. ROGERS, D.A. SEEMANN and A.D. COLLINS. 1985. Continent—ocean transect B1: Intermontane Belt (Skeena Mountains) to Insular Belt (Queen Charlotte Islands). *Geological Society of America, Decade of North American Geology*.

APPENDIX III

Permanent Staff 1985 Institute of Ocean Sciences

A. Department of Fisheries and Oceans

Director-General

Mann, C.R.; B.Sc., M.Sc. (N.Z.), Ph.D. (Brit. Col.),

D. Eng. (N.S. Tech), F.R.S.C.

* Van Dusen, T.S.

** McDonald, L.J.

Management Services Division

Chief of Division:

Todd, N.A.; B.Sc. (Glasgow), M.A. (Carleton)

Anderson, M.

Coldwell, J.H.

Cooper, B.J.

Curtis, J.N.

Doxey, K.

Drysdale, A.E.

* Firth, C.

Gent, C.E.

Grills, C.J.

Hanmer, M.P.

Hope, T.

Keding, L.M.

Kroeger, K.

Kusch, R.R.

Lafortune, A.J.; B.A. (Manitoba)

Lapp, B.I.; B.A. (Victoria)

Lohrmann, B.A.; B.Sc. M.Sc. (Guelph)

MacMillan, B.C.

Oakfield, C.L.

Sabourin, J.T.

Smith, K.R.

Thomson, L.S.C.; B.A. (Sask.), B.L.S. (Brit. Col.)

Tillie, D.G.

Van Eyk, W.J.

Watts, F.

Commissionaires:

Sgt. Price, D.W.

Sgt. Hull, N.S.B.

Comm. Alexander, F.

Comm. Ashton, B.

Comm. Hill, E.

Comm. Moe, L.

Comm. Moffat, H.

Comm. Morris, R.

* Comm. Trerice, L.

Comm. Wilson, W.

* Left in 1985

** Joined in 1985

Personnel

Regional Personnel Manager:
Hamilton, K.R.; B.A. (Brit. Col.)

Groves, L.D.; Dip. (Victoria)
Knapp, B.M.
Linguanti, S.C.
Olauson, E.J.
Renstrom, M.
Trentelmann, E.

Hydrography

Director of Hydrography:

* Bolton, M.; C.L.S.
** O'Connor, A.D.; C.L.S.

Ages, A.B.; B.A.Sc., M.A.Sc. (Brit. Col.), P. Eng.
Bell, R.D.
Canning, B.
Chan, L.M.
Chapeskie, R.E.
Coldham, F.A.
Collins, T.
Crawford, W.R.; B.Sc., M.A.Sc. (Waterloo), Ph.D. (Brit. Col.)
Crowley, J.V.; C.L.S.
Crowther, W.S.; CC (Ont. Inst. of Chartered Cartographers)
Curran, T.A.; B.A.Sc. (EE), M.Sc. (Brit. Col.), P. Eng.
Czotter, K.L.; Dip. BCIT
Dobson, D.G.
Dorosh, L.W.; Dip. BCIT
Douglas, A.; B.Sc. (Victoria)
Earl, E.L.P.
Eaton, G.H.; Dip. BCIT, B.Sc. (UNB), C.L.S.
Farmer, P.M.
Fisher, D.L.
Galloway, J.L.; B.A.Sc. (EE), M.A.Sc. (EE) (Brit. Col.), P. Eng.
Gould, J.M.
** Gresham, G.E.
Halcro, K.; Dip. BCIT
Hare, R.; Dip. BCIT
Hermiston, F.V.
Hinds, E.W.; Dip. BCIT
Hinds, S.D.
Hohl, M.
Hollinger, C.; Dip. BCIT
Holman, K.R.
Huggett, W.S.; Master (FG), C.L.S.
Jackson, D.M.; B.Sc. (Victoria)
Jackson, T.L.

Jennings, M.J.
Jodrell, D.A.
Johnson, B.A.; Dip. BCIT
Kenny, B.
** Kerr, B.; Dip. Seneca, B.A. (York)
Kidson, G.G.
Korhonen, R.K.
Larkin, J.B.; B.Sc. (PEI)
Lee, K.S.
Lewis, B.V.; Dip. BCIT
* Lloyd, I.M.; Dip. BCIT
Loschiavo, R.; Dip. BCIT
Lusk, B.C.; Master (350T), C.L.S.
Lyngberg, K.; Dip. BCIT
Lyon, A.G.
MacPhail, G.
* McGregor, B.G.; Dip. BCIT
Milner, P.R.; Dip. BCIT
Moody, A.E.
*** Mortimer, A.R.; Master (FG), B.Sc. (Victoria), C.L.S.
Muse, R.A.; Trade Cert. CAF
Nowak, C.; Dip. BCIT
** Parkhouse, P.J.
Parks, J.R.; B.A.Sc. (EE) (Brit. Col.)
Pfluger, H.A.
Philp, A.R.
Pickell, L.M.
Pierce, R.A.
Popejoy, R.D.
** Prince, D.W.; B.A. (Victoria)
Rapatz, W.J.; B.Sc. (Victoria), C.L.S.
Raymond, A.R.; Dip. (Algonquin College)
Redman, D.
Richardson, G.E.; C.L.S.
* Roberts, J.W.; Master (FG), Cdr. RCN (Ret'd)
Ross, A.D.; CC (Ont. Inst. of Chartered Cartographers)

Sadlish, J.P.
 Sandilands, R.W.; Lt. (H) RN (Ret'd), C.L.S. FRGS
 Sargent, E.D.; Dip. BCIT
 ** Schlagintweit, G.E.; Dip. BCIT
 Schofield, A.J.
 Schofield, B.D.; B.Sc. (Victoria)
 Smedley, A.J.; L. Cdr. RCN (Ret'd)
 Smith, A.; Master (FG)
 Smith, G.R.; B.A.Sc. (ME) (Brit. Col.), P. Eng.
 Steeples, J., Cert. Mech. Eng. (Edinburgh)
 Stephenson, F.E.; B.Sc. (Victoria)
 Taylor, W.R.; Dip. BCIT
 Thompson, L.G.
 Thomson, A.D.; Dip. BCIT
 Tuck, B.D.; B.Sc. (Victoria)

Vear, M.
 Ward, M.M.; Dip. BCIT, B.A. (Lakehead)
 Watt, B.M.
 ** Wells, I.C.; B.Sc. (Victoria)
 Whincup, G.
 Woods, M.V.; Dip. BCIT, B.Sc. (Calgary)
 Woodward, M.J.; B.Sc. (Victoria), M.Sc. (Toronto)
 Woolley, R.; Dip. BCIT
 Yee, J.

* Left in 1985
 ** Joined in 1985
 *** Seconded to Quebec Region

Ship Division

Regional Marine Superintendent:
 Parkinson, R.W.; Engineer 1st Class, Member;
 Institute of Marine Engineers

Fitch, L.A.H.; Master, H.T.; Assist. Marine
 Superintendent
 Doyle, D.A.; Secretary
 Craton, M.; Administrative Clerk

CSS JOHN P. TULLY

Newton, B.L.; Master F.G., Master
 Coombes, A.S.; ON.1, Chief Officer
 Campbell, J.D.; 2nd Officer
 Purdie, J.; 3rd Officer
 Pereira, P.B.; Eng. 1st Class Combined, Chief
 Engineer
 Stanway, J.D.; Eng. 2nd Class Motor, 2nd Engineer
 Murphy, P.J.
 Kirkby, D.
 Garneau, G.C.
 Law, S.
 Keene, A.R.
 Graham, D.B.
 Aucoin, A.E.
 Clark, L.E.
 Boughton, D.G.E.
 Napier, J.W.
 Prunkl, W.J.
 Manifold, G.C.
 Heesterman, D.N.
 McRae, A.R.
 Smart, T.R.
 Brown, D.G.
 Contois, W.M.

CSS PARIZEAU

Chamberlain, A.G.; Master F.G., Master
 Gimbel, K.; W.K.M., 3rd Officer
 Winterburn, G.; Eng. 1st Class Motor Chief Engineer
 Tran, K.H.; Eng. 2nd Class Motor, Senior 2nd
 Engineer
 Dowhy, J.; Eng., 3rd Engineer
 Carter, R.A.
 Purdie, D.; Eng. 4th Class Motor, 4th Engineer
 Palmer, S.; Supply Officer
 Begoray, N.
 Weston, A.
 Cooke, B.E.
 Waistell, G.A.
 Waterfall, J.P.
 Camiot, M.
 Smith, J.R.
 Springett, B.R.
 Brown, J.D.
 Fidler, M.J.
 Keene, A.
 Fowke, K.
 Knoblauch, D.
 Laforest, B.G.
 Begin, P.
 Kirk, M.J.
 Greene, J.S.

CSS VECTOR

MacKenzie, R.W.; Master H.T., Master
Wheeler, M.G.; Master H.T., 1st Officer
Pearson, R.; Eng. 3rd Class Motor, Chief Engineer
Braithwaite, P.M.
Robie, D.J.
Anderson, D.D.
Simpson, F.W.
Lavigne, R.
McKechnie, D.G.
Burns, R.G.
White, R.M.
Scoones, A.E.
Fisher, P.R.
Cadorin, G.D.

CSS RICHARDSON

LeGarff, J.; W.K.M., Master
Jamieson, T.A.
Scott, R.C.

PISCES IV

Chambers, F.J.; Chief Pilot
Taylor, R.H.
Witcombe, A.E.
Oszust, J.S.
Shepherd, K.
Holland, R.R.

SHORE PARTY AND RELIEF POOL

Frost, P.A.
Elliott, H.G.; O.N.II
Beebe, E.; Eng. 4th Class Motor
Thompson, D.
Moore, A.; Eng. 4th Class Motor
Allison, G.R.
Lovelace, R.S.
Sanderson, R.L.
Simmons, B.R.
Williams, L.

DECK MACHINERY

Bradbury, J.D.

INSTITUTE WORKSHOPS

Smith, F.V.; Supervisor
McNeill, J.; Foreman
Badminton, E.C.
Barlow, L.
Bell, W.
Ennis, J.F.
Green, G.E.
Gurney, J.P.
Nelson, B.J.
Noren, R.J.S.
Smith, G.J.
Thompson, B.R.
Williams, P.D.

Ocean Information

Chief of Division:

** Wilson, R.C.H.; B.Sc. (Simon Fraser), M.S. (Western Washington)

Giovando, L.F.; B.A., M.A., Ph.D. (Brit. Col.)

Glover, K.T., B.A. (UNB)

*** Pitcher, J.A.

Smiley, B.C.; B.Sc., M.Sc. (Alberta)

** Joined in 1985

*** Educational Leave

Ocean Chemistry Division

Chief of Division:

Wong, C.S.; B.Sc., M.Sc. (Hong Kong), Ph.D. (Scripps),
Dip. Mar. Sc. (UNESCO), F.R.S. Chem. (U.K.),
F.C.I.C.

Bellegay, R.D.; Dip. NAIT, Assoc. Deg. in
Oceanography (Shoreline Community College,
Seattle)

Cretney, W.J.; B.Sc., Ph.D. (Brit. Col.)
Johnson, W.K.; Dip. BCIT
Macdonald, D.M.; B.A.Sc. (Brit. Col.), Dip. (Camosun College)
Macdonald, R.W.; B.Sc., Ph.D. (Dalhousie)
McLaughlin, F.A.; B.Sc. (Victoria)
O'Brien, M.C.; B.Sc. (Alberta)
Paton, D.W.; B.Sc. (Brit. Col.)
Poulin, J.G.
Smith, G.L.; Dip. NAIT
Soutar, T.J.; Dip. BCIT
Thompson, J.A.J.; B.Sc. (McMaster), Ph.D. (Alberta), F.C.I.C.
Whitney, F.A.; B.Sc. (Brit. Col.)

Ocean Physics Division

Chief of Division:
Garrett, J.F.; B.A. (Harvard), Ph.D. (Brit. Col.)

Bell, W.H.; B.A.Sc. (Brit. Col.), M.Sc. (Hawaii), P. Eng.
Bennett, A.F.; B.Sc. (U. of Western Australia), M.S., Ph.D. (Harvard)
Bigham, R.W.
Budgell, W.P.; B.A.Sc. (Waterloo), M.Eng. (McMaster), Ph.D. (Waterloo)
Chase, G.W.; Dip. BCIT
Cooke, R.A.; Dip. RCC
Crean, P.B.; B.Sc. (Dublin), M.A.Sc. (Toronto), Ph.D. (Liverpool)
de Jong, C.
Delacretaz, A.
Farmer, D.M.; B.Comm., M.Sc. (McGill), Ph.D. (Brit. Col.)
Francis, D.B.; B.Sc. (Victoria)
Freeland, H.J.; B.A. (Essex), Ph.D. (Dalhousie)
Gargett, A.E.; B.Sc. (Manitoba), Ph.D. (Brit. Col.)
Gower, J.F.R.; B.A., M.A., Ph.D. (Cantab)
Henry, R.F.; B.Sc. (Edinburgh), Ph.D. (Cantab)
Holloway, G.; B.A., M.S., Ph.D. (California)
Johnston, P.
Kamitakahara, G.R.; B.Sc. (Toronto)
Koppel, A.W.
Kimber, P.M.
Lake, R.A.; B.Sc. (Brit. Col.), M.Sc. (Washington)
Lee, A.Y.P.; B.Sc. (Victoria)
Lewis, E.L.; B.Sc., M.Sc., Ph.D. (London)
Love, J.
Mathias, A.L.
* Meikle, J.H.
Melling, H.; B.Sc., M.Sc., Ph.D. (Toronto)
Minkley, B.G.; Dip. BCIT

Miyake, M.; B.S. (EE) (Drexel), M.S., Ph.D. (Washington)
Moonie, J.A.
Moorhouse, S.W.
Murty, T.S.; B.Sc., M.Sc. (Andhra), M.S., Ph.D. (Chicago)
Perkin, R.G.; B.A.Sc., M.Sc. (Brit. Col.)
Quay, L.
Richards, D.L.
Spearing, L.A.F.; B.Sc. (Brit. Col.)
Stickland, J.A.
Stucchi, D.J.; B.A.Sc. (York), M.Sc. (Dalhousie)
Sudar, R.B.; B.A.Sc. (Toronto)
Tabata, S.; B.A., M.A. (Brit. Col.), D.Sc. (Tokyo)
Teichrob, R.C.; Dip. BCIT
Thomson, R.E.; B.Sc., Ph.D. (Brit. Col.)
Topham, D.R.; D.L.C., D.C.A.E., Ph.D. (Loughborough)
Wallace, J.S.
Wu, L.S.C.; B.Sc. (Brit. Col.)

* Left in 1985

Computing Services

Head:

** Teng, K.; B.A.Sc., M.A. (Brit. Col.)

Acting Head:

Johns, R.E.; B.Sc. (Victoria), M.Sc. (Brit. Col.)

Douglas, A.N.; B.Sc. (Victoria)

Foreman, M.G.; B.Sc. (Queen's), M.Sc. (Victoria)

Green, J.W.; B.Sc. (Victoria)

Lee, D.K.; B.S. (Chosun-Korea), M.S. (Oregon)

Lee, K.S.; B.Sc. (Victoria)

Linguanti, J.; B.Sc. (Victoria)

Ma, A.C.; B.Sc. (Victoria)

** Oraas, S.R.; B.A.Sc., M.A.Sc. (Brit. Col.)

Page, J.S.; B.Sc. (Brit. Col.)

Smith, L.J.; B.Sc. (Simon Fraser)

Woppard, A.L.; B.Sc. (Victoria)

** Interchange Program

** Personal leave

Ocean Ecology Division

Chief of Division:

Brinkhurst, R.O.; B.Sc., Ph.D., D.Sc. (London)

** Brown, R.M.; B.Sc. (Brit. Col.)

Denman, K.L.; B.Sc. (Calgary), Ph.D. (Brit. Col.)

Forbes, J.R.; B.Sc. (Carleton), M.Sc. (Alberta)

Mackas, D.L.; B.S., M.S. (Washington), Ph.D.
(Dalhousie)

Moore, D.F.; B.Sc. (McMaster)

Stone, M.

** Joined in 1985

Post Doctoral Fellows

Altman, D.B.; B.Sc. (Mech. Eng.) (Cornell), M.Sc.
(California), M.B.A. (Colorado), Ph.D. (California)

Dumais, J.F.; B.Sc. (Quebec), M.Sc. (Alberta), Ph.D.
(Alberta)

McIntosh, P.C.; B.Sc. (Monash), Ph.D. (Monash)

* Nemec, A.F.; B.Sc. (Victoria), M.Sc. (Victoria), Ph.D.
(Washington)

Nurse, C.R.; B.A. (Oxford), M.A. (Oxford), Ph.D. (Brit.
Col.)

Simard, Y.S.; B.Sc. (Laval), Ph.D. (Laval)

* Left in 1985

B. Department of Environment

Atmospheric Environment Service

McBean, G.A.; B.Sc. (Brit. Col.), M.Sc. (McGill), Ph.D.
(Brit. Col.)

Canadian Wildlife Service

Vermeer, K.; M.Sc. (Brit. Col.), Ph.D. (Alberta)

C. Department of Energy, Mines and Resources

Pacific Geoscience Centre

Director:

Hyndman, R.D.; B.A.Sc., M.A.Sc. (Brit. Col.), Ph.D.
(A.N.U.)

Head, Marine Geology (G.S.C.):

Currie, R.G.; B.Sc., M.Sc. (Brit. Col.)

Chief Scientist, Pacific Geophysics Division (E.P.B.):

Law, L.K.; B.A.Sc. (Toronto), M.Sc. (Western Ontario),
Ph.D. (Cantab)

Special Projects Officer (E.P.B.):

Boyd, J.B.

Administrative Group

McCormick, J.K., Head; B.A., M.A.I. (McGill)

** Brown, M.
Chisholm, D.M.

* McDonald, L.J.

** Jenner, E.A.

McLean, A.

Meeres, M.

Price, W.

* Left in 1985

** Joined in 1985

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Ontario), Ph.D. (Cantab)

Auld, D.R.; B.A.Sc. (Brit. Col.)

DeLaurier, J.M.; B.Sc. (Queen's)

Irving, E.; M.A., Sc.D. (Cantab), D.Sc. (Hon., Carleton),
F.R.S.C., F.R.S.

Wynne, P.J., B.Sc. (Queen's), M.Sc. (Memorial)

Gravity, Geothermics and Geodynamics Section

Sweeney, J.F. Head; B.A., M.A., Ph.D. (S.U.N.Y., Buffalo)

* Riddihough, R.P., Head; B.Sc. (King's College, London), D.I.C., M.Sc. (Imperial College, London), Ph.D. (U. of London)

Bentkowski, W.H.; B.Sc. (Western Ontario)

Dragert, H.; B.Sc. (Toronto), M.Sc., Ph.D. (Brit. Col.)

Lewis, T.J.; B.A.Sc., M.Sc. (Brit. Col.), Ph.D. (Western Ontario)

Seemann, D.; B.Sc. (Brit. Col.)

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Marine Geology Subdivision

Bornhold, B.D.; B.Sc. (Waterloo), M.A. (Duke), Ph.D. (M.I.T., Wood's Hole)

Cameron, B.E.B.; B.Sc., M.Sc. (Alberta), P.Geol.

Hamilton, T.; B.Sc. (Case Western Reserve), A.M. (Indiana), Ph.D. (Alberta)

* Luternauer, J.L.; B.A. (Colby), M.A. (Duke), Ph.D. (Brit. Col.)

* McLaren, P.; B.Sc., M.Sc. (Calgary), Ph.D. (South Carolina)

Yorath, C.J.; B.Sc. (Brit. Col.), M.Sc. (Alberta), Ph.D. (Queen's)

Pacific Geophysics Division

Seismology Section

Weichert, D.H., Head; B.A.Sc., M.Sc., Ph.D. (Brit. Col.)

Davis, E.E., B.Sc. (U.C., Santa Barbara), Ph.D. (Washington)

Gregory, M.J.

Horner, R.B.; B.Sc. (Manitoba)

Rogers, G.C.; B.Sc. (Brit. Col.), M.Sc. (Hawaii), Ph.D. (Brit. Col.)

Sawyer, B.; B.F.A. (Victoria)

Technical Support Groups

Geological Survey of Canada

Forbes, T.; B.Sc. (Simon Fraser)

Frydecky, I.I.; B.A.Sc., M.A.Sc. (Brit. Col.), P. Eng.

Hill, W.A.M.; Dip. (BCIT)

Horel, G.C.; B.Sc. (Royal Roads)

Jewsbury, G.C.; B.Sc. (Victoria)

Johns, M.; B.Sc. (Brit. Col.)

McDonald, R.D.; B.A.Sc. M.A.Sc. (Brit. Col.)

Earth Physics Branch

Bone, M.N., Head; B.A.Sc. (Toronto)

Baldwin, R.E.; B.Sc. (Wyoming), M.Sc. (Alberta)

* Bennetts, H.J.

Bowker, D.

Whitford, H.A.

Wilde, M.H.J.

Post Doctoral Fellows

Brandon, M.; B.Sc. (U.C., Santa Cruz), M.Sc., Ph.D.
(Washington)

** Globerman, B.R.; B.Sc. (Washington), M.Sc. (Western
Washington), Ph.D. (U.C., Santa Cruz)

Massey, N.; B.Sc. (Leeds), Ph.D. (McMaster)
Nobes, D.; B.Sc., M.Sc. Ph.D. (Toronto)

* Villinger, H.; Diplom. Ph.D. (T.U. Berlin)

* Left in 1985

** Joined in 1985

Visitors

Barrie, V.; Memorial University

Brandon, L.; COGLA

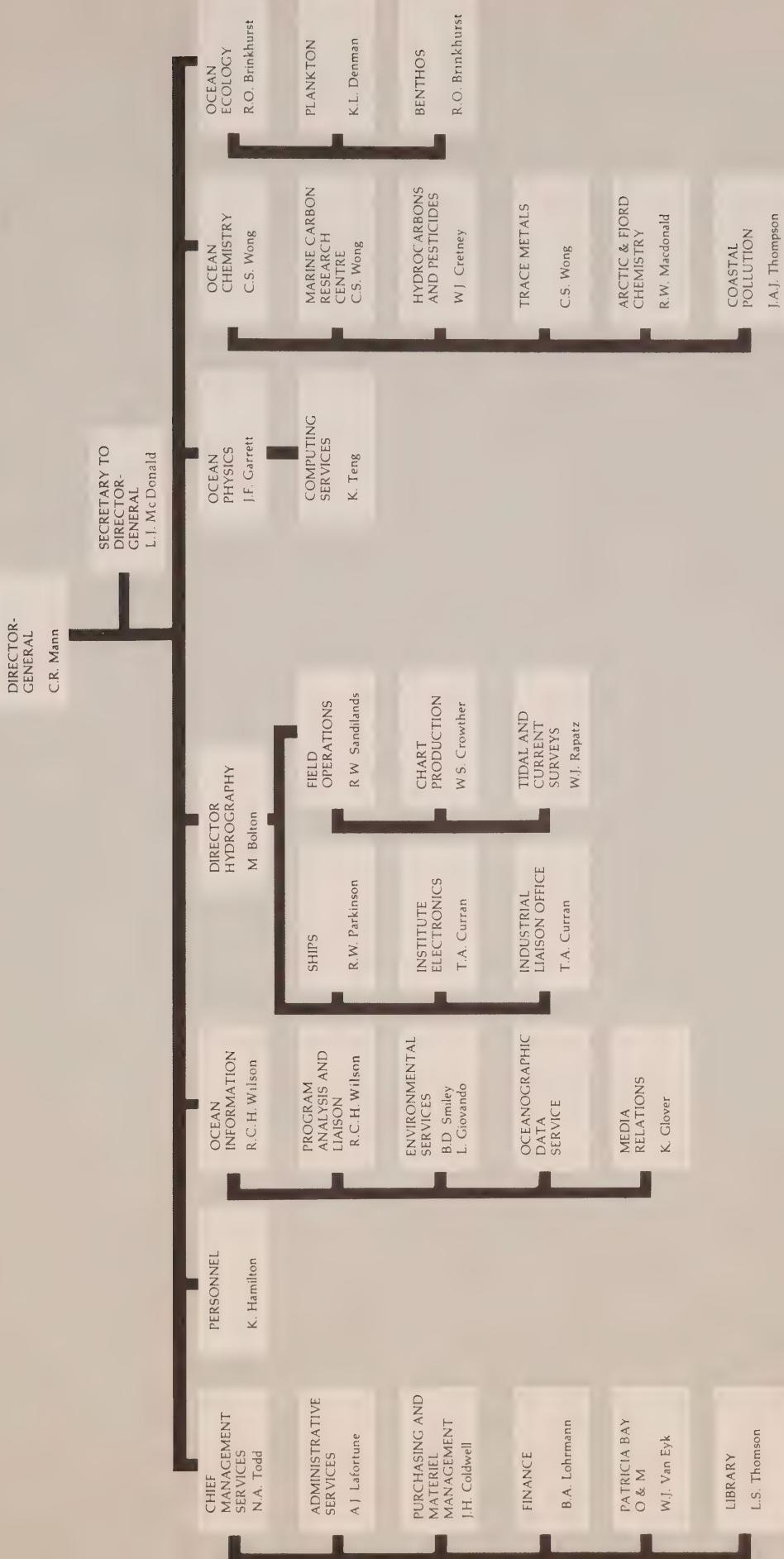
Keen, M.J.; Atlantic Geoscience Centre

Smith, W.; D.S.I.R.; New Zealand

Wahlstrom, R.; University of Uppsala, Sweden

Organization Chart

Department of Fisheries and Oceans



**1985
ANNUAL REVIEW
OF ACTIVITIES**



Government
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du Canada

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PATRICIA BAY, SIDNEY, B.C.

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